A
Project Report on

CFD Modeling of Multiphase Fluidized Bed

In partial fulfillment of the requirements of

Bachelor of Technology (Chemical Engineering)

Submitted By

Debasish Mohapatra (Roll No.10300002)
Kapil Rakh (Roll No.10300003)
Session: 2006-07

Department of Chemical Engineering
National Institute of Technology
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Under the guidance of

Prof. (Dr.) G. K. Roy

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CERTIFICATE

This is to certify that that the work in this thesis report entitled “CFD Modeling of Multiphase Fluidized Bed” submitted by Debasish Mohapatra and Kapil Rakh in partial fulfillment of the requirements for the degree of Bachelor of Technology in Chemical Engineering Session 2003-2007 in the department of Chemical Engineering, National Institute of Technology Rourkela, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any other University /Institute for the award of any degree.

Date:

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ABSTRACT

CFD is predicting what will happen, quantitatively, when fluids flow, often with the complications of, simultaneous flow of heat, mass transfer (eg perspiration, dissolution), phase change (eg melting, freezing, boiling), chemical reaction (eg combustion, rusting), mechanical movement (eg of pistons, fans, rudders), stresses in and displacement of immersed or surrounding solids. Knowing how fluids will flow, and what will be their quantitative effects on the solids with which they are in contact, assists chemical engineers to maximize the yields from their reactors and processing equipment at least cost; risk.

CFD uses a computer to solve the relevant science-based mathematical equations, using information about the circumstances in question. Its components are therefore: the human being who states the problem, scientific knowledge expressed mathematically, the computer code (ie software) which embodies this knowledge and expresses the stated problem in scientific terms, the computer hardware which performs the calculations dictated by the software.

Our project involves determining the validity of predictions made by CFD software (FLUENT) on three phase fluidization in a cylindrical bed by comparing with the practical results from the experiment conducted in lab. By this we were successfully able to predict the relationship of pressure drop and bed height vs. superficial velocity for different bed materials and liquid of different viscosities.

For chemical processes where mass transfer is the rate limiting step, it is important to be able to estimate the gas holdup as this relates directly to the mass transfer. Although gas hold up in three-phase fluidized bed has received significant attention , most previous work has utilized air , water and small beads as gas, liquid and solid respectively. The gas hold up in such systems is often considerably lower than for pilot-plant or industrial-scale units. In our project we have used glycerol of different concentrations to be able to maximize the usefulness of the result.

CHAPTER 1

LITURATURE REVIEW

1.1 INTRODUCTION

Gas-liquid-solid fluidization became a subject for fundamental research only about three decades ago. Considerable progress has been made with respect to an understanding of the phenomenon of gas-liquid-solid fluidization since then. The successful design and operation of a gas-liquid-solid fluidized bed system depends on the ability to accurately predict the fundamental properties of the system. Specially, the hydrodynamics, the mixing of individual phases, and the heat and mass transfer properties. Gas-liquid-solid (or gas-slurry-solid in a broad sense) fluidized beds have emerged in recent years as one of the most promising devices for three-phase operations. The term" three-phase fluidization" requires some explanation, as it can be used to denote a variety of rather different operations. The three-phase is referred to be gas, liquid and particulate solids, though recently investigations have been performed using two immiscible liquids and particulate solids.

A three-phase fluidized bed is established when a dispersed solid is fluidized by a co-current upward flow of gas and liquid. The industrial importance of three-phase fluidized bed has been studied by many authors [5]. Gas-liquid-solid fluidization is defined as an operation in which a bed of solid particles is suspended in gas and liquid media due to the net drag force of the gas and/or liquid flowing opposite to the net gravitational force or buoyancy force on the particles. Such an operation generates considerable, intimate contact among the gas, liquid and solid particles in these systems and provides substantial advantages for applications in physical, chemical or biochemical processing involving gas, liquid and solid phases.

The state of the gas-liquid-solid fluidization is strongly dependent on the geometry of the bed, methods of gas-liquid injection, and the presence of a retaining grid or internals. This is exemplified by the operation of a tapered fluidized bed, spouted bed, semi-fluidized bed, and draft tube spouted bed. The tapered fluidized bed uses a tapered column, which diverges, at a small angle in the upward direction. The upper part of the bed is at or near the state of incipient fluidization and behaves similarly to the packed bed part of the semi-fluidized bed. In a spouted bed, gas and liquid are introduced into the bed through a gas-liquid injector located at the bottom of the bed. The semi-fluidized bed is formed when a mass of fluidized particles is compressed against a porous restraining at the top grid resulting in the creation of a fluidized bed and a fixed bed in series within a single vessel. The internal structure of a semi-fluidized bed can easily altered to create an optimal configuration. This unique feature allows the semi-fluidized bed to be utilized for a wide range of physical, chemical and bio chemical applications

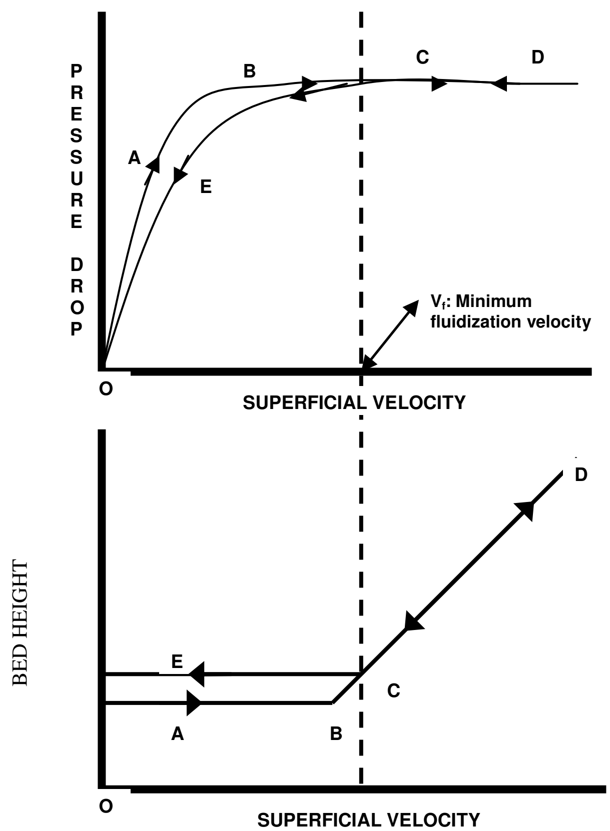


Fig-1.1-Variation of pressuredrop and bed height with respect to superficial gas velocity

1.2 MODES OF OPERATION

Gas-liquid-solid fluidization can be classified mainly into four modes of operation. These modes are co-current three-phase fluidization with liquid as the continuous phase (mode I-a); co-current three-phase fluidization with gas as the continuous phase (mode-I-b); inverse three-phase fluidization (mode II-a); and fluidization represented by a turbulent contact absorber (TCA) (mode II-b). Modes II-a and II-b are achieved with a countercurrent flow of gas and liquid. Due to the complex nature of three-phase fluidization, however, various method are possible in evaluating the operating and design parameters for each mode of operation.

Based on the differences in flow directions of gas and liquid and in contacting patterns between the particles and the surrounding gas and liquid, several types of operation for gas-liquid-solid fluidizations are possible. Three-phase fluidization is divided into two types according to the relative direction of the gas and liquid flows, namely, co-current three-phase fluidization and co-current three-phase fluidization [10]. This is shown in **figure: 1.2.** shown on the next page.

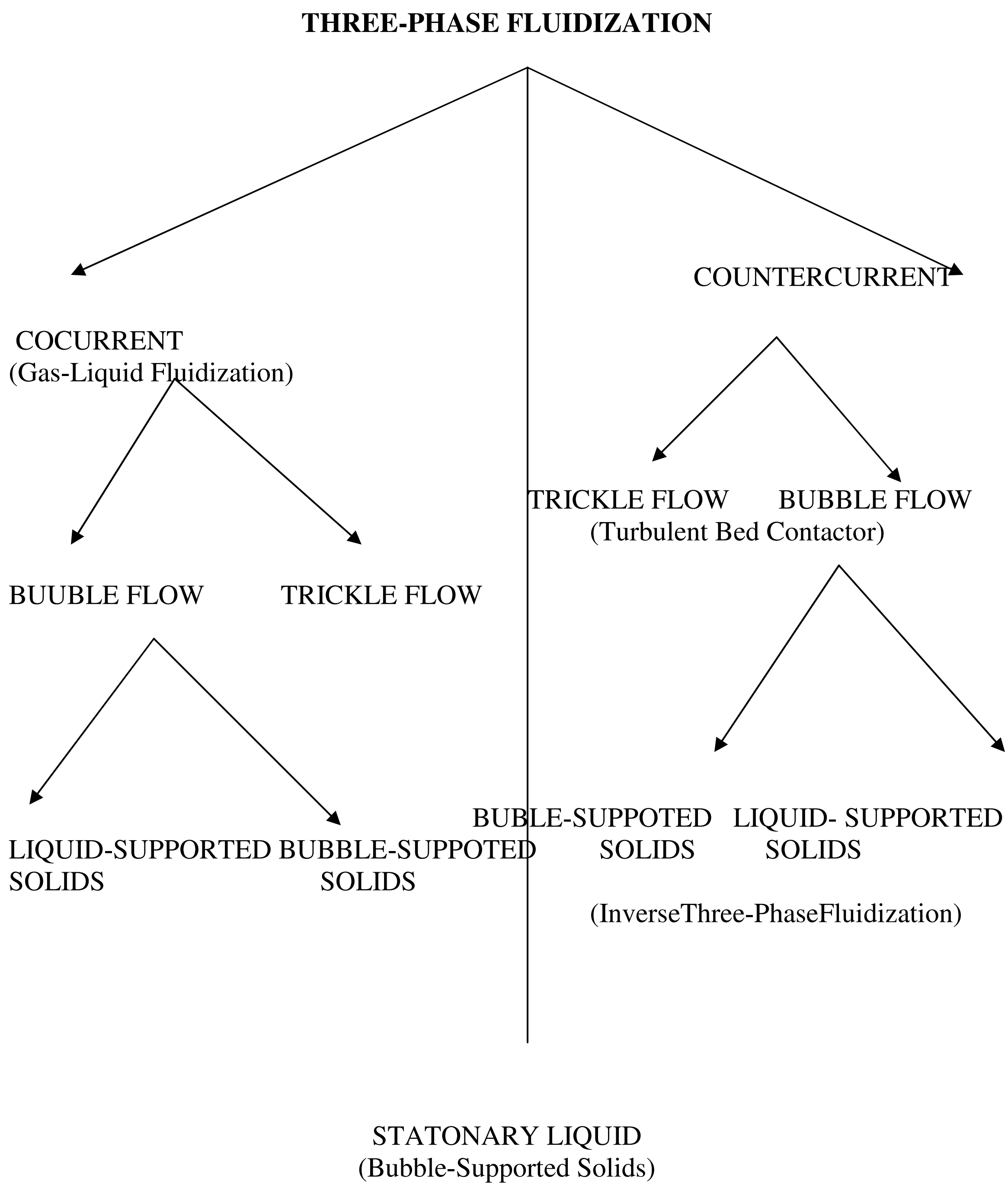


Figure: 1.2, Taxonomy of three-phase fluidized bed.

1.3 VARIABLES AFFECTING THE QUALITY OF FLUIDIZATION:

Some of the variables affecting the quality of fluidization are

- Fluid inlet: It must be designed in such a way that the fluid entering the bed is well distributed.
- Fluid flow rate: It should be high enough to keep the solids is suspension but it should not be so high that the fluid channeling occurs.
- Bed height: With other variables remaining constant, the greater the bed height, the more difficult it is to obtain good fluidization.
- Particle size: It is easier to maintain fluidization quality with particles having a wide range than with particles of uniform size.
- Gas, Liquid and solid densities: The closer the relative densities of the gas, liquid and the solid , the easier is to maintain smooth fluidization.
- Bed internals: In commercial fluidizers internals are provided to perform the following functions.
    1. To prevent the growth of bubble sizes
    2. To prevent lateral movement of fluid and solids.
    3. To prevent slug formation
    4. To prevent elutriation of fine particles

1.4 APPLICATIONS

Gas-liquid-solid fluidized beds have emerged in recent years as one of the most promising devices for three-phase operations. Such devices are of considerable industrial importance as evidenced by their wide use for chemical, petrochemical and biochemical processing. As three-phase reactors, they have been employed in hydrogenation and hydrosulferization of residual oil for coal liquefaction, in turbulent contacting absorption for flue gas desulphurization, and in the bio-oxidation process for wastewater treatment. Three-phase fluidized beds are also often used in physical operations.

The application of gas-liquid-solid fluidized bed systems to biotechnological processes such as fermentation and aerobic wastewater treatment has gained considerable attention in recent years. In these three-phase biotechnological processes, biologically catalytic agents, either enzymes or living cells, are incorporated into the solid phase through immobilization techniques. Typically, enzymes or living cells are entrapped within natural or synthetic polymer gel particles or are attached to the surface of solid particles. Three-phase fluidized beds enjoy widespread use in a number of applications including hydro treating and conversion of heavy petroleum and synthetic crude, coal liquefaction, methanol production, conversion of glucose to ethanol and various hydrogenation and oxidation reaction.

Fluidized bed units are also found in many plant operations in pharmaceuticals and mineral industries. Fluidized beds serve many purposes in industry, such as facilitating catalytic and non-catalytic reactions, drying and other forms of mass transfer. They are especially useful in the fuel and petroleum industry for things such as hydrocarbon cracking and reforming as well as oxidation of naphthalene to phathalic anhydride (catalytic), or coking of petroleum residues (non-catalytic). Catalytic reactions are carried out in fluidized beds by using a catalyst as the cake in the column, and then introducing the reactants. In catalytic reactions, gas or liquid is passed through a dry catalyst to speed up the reaction.

CHAPTER 2

COMPUTATIONAL FLUID DYNAMICS

CFD is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the millions of calculations required to simulate the interaction of fluids and gases with the complex surfaces used in engineering. However, even with simplified equations and high speed supercomputers, only approximate solutions can be achieved in many cases. More accurate codes that can accurately and quickly simulate even complex scenarios such as supersonic or turbulent flows are an ongoing area of research.

2.1 BACKGROUND

The fundamental basis of any CFD problem is the Navier-Stokes equations, which define any single-phase fluid flow. These equations can be simplified by removing terms describing viscosity to yield the Euler equations. Further simplification, by removing terms describing vorticity yields the Full Potential equations. Finally, these equations can be linearized to yield the Linearized Potential equations.

2.2 METHODOLOGY:

In all of these approaches the same basic procedure is followed.

1. The geometry (physical bounds) of the problem is defined.
2. The volume occupied by the fluid is divided into discrete cells (the mesh).
3. The physical modelling is defined - for example, the equations of motions + enthalpy + species conservation
4. Boundary conditions are defined. This involves specifying the fluid behaviour and properties at the boundaries of the problem. For transient problems, the initial conditions are also defined.
5. The equations are solved iteratively as a steady-state or transient.
6. Analysis and visualization of the resulting solution.

2.3 HOW DOES A CFD CODE WORK?

CFD codes are structured around the numerical algorithms that can be tackle fluid problems. In order to provide easy access to their solving power all commercial CFD packages include sophisticated user interfaces input problem parameters and to examine the results. Hence all codes contain three main elements:

1. Pre-processing.

2. Solver

3. Post –processing.

2.3.1 Pre-Processing:

Preprocessor consist of input of a flow problem by means of an operator –friendly interface and subsequent transformation of this input into form of suitable for the use by the solver.

The user activities at the Pre-processing stage involve:

- Definition of the geometry of the region: The computational domain.
- Grid generation the subdivision of the domain into a number of smaller, non-overlapping sub domains (or control volumes or elements Selection of physical or chemical phenomena that need to be modeled).
- Definition of fluid properties
- Specification of appropriate boundary conditions at cells, which coincide with or touch the boundary.

The solution of a flow problem (velocity, pressure, temperature etc.) is defined at odes inside each cell. The accuracy of CFD solutions is governed by number of cells in the grid. In general, the larger number of cells better the solution accuracy. Both the accuracy of the solution & its cost in terms of necessary computer hardware & calculation time are dependent on the fineness of the grid. Efforts are underway to develop CFD codes with a (self) adaptive meshing capability.

Ultimately such programs will automatically refine the grid in areas of rapid variation.

2.3.2 Solver:

These are three distinct streams of numerical solutions techniques: finite difference, finite volume& finite element methods. In outline the numerical methods that form the basis of solver performs the following steps

- Approximation of unknown flow variables by means of simple functions.
- Discretization by substitution of the approximation into the governing flow equations &* subsequent mathematical manipulations.
- Solution of the algebraic equations.

2.3.3 Post-Processing:

As in the pre-processing huge amount of development work has recently has taken place in the post processing field. Owing to increased popularity of engineering work stations, many of which has outstanding graphics capabilities, the leading CFD are now equipped with versatile data visualization tools. These include

- Domain geometry & Grid display.
- Vector plots.
- Line & shaded contour plots.
- 2D & 3D surface plots.
- Particle tracking.
- View manipulation (translation, rotation, scaling etc.)

2.4 GAMBIT (CFD PREPROCESSOR)

It is a software package designed to help analyst and designers build and mesh models for CFD and other scientific applications.

The Gambit graphical user interface makes the basic steps of:

- Building.

- Meshing,
- Assigning zones type to a model

Gambit has following advantages:

1. Ease of use: It is user friendly
2. CAD/CAE Integration: Gambit can import geometry from any CAD/CAE software
3. Fast Modeling: It provides a concise and powerful set of solid modeling based geometry tools
4. CAD cleanup: Gambit's semiautomatic cleanup tools can be used to repair and prepare the geometry for high quality meshing.
5. Intelligent Meshing: Different CFD problems require different mesh types. Gambit provides a wide variety of meshing tools.

Step 1 : Building the geometry

There are two approaches to build the geometry

→ Top Down

→ Bottom Up

Top Down : construct the geometry by creating volumes (bricks ,cylinder etc) and then multiplying them through boolean operation.

Bottom Up : create vertices, then creating edges from vertices, then connect the edges to create faces and then connect the faces to create volume.

Step 2 : Meshing the model

Meshing can be done in different ways:

→ Triangular, quadrilateral, hexahedral, tetrahedral, prism etc.

→ structured and unstructured mesh.

Step 3 : Specifying zones type

Zone type specification define the physical and operational characteristics of the model at its boundaries and within specific region of its domain. There are two classes of zone type specification

→ Boundary type

→ continuum type

Boundary type -:

In this type specifications, such as well, vent or inlet, define the characteristics of the model at its external or internal boundaries.

Continuum type -:

In this type specification, such as fluid or solid, define the characteristics of the model within specified regions of its domain. e.g. if you assign a fluid continuum type specification to a volume entity, the model is defined such that equations of momentum, continuity and species transport apply at mesh nodes or cells that exist within the volume. Conversely if you assign a solid continuum type specification to a volume entity, only the energy and species transport equations (without convection) apply at the mesh nodes or cells that exist within the volume.

Fluid zone = group of cells for which all active equations are solved.

Solid zone = group of cells for which only heat conduction problem solved.
No flow equations solved.

2.5 ADVANTAGES OF CFD:

Major advancements in the area of gas-solid multiphase flow modeling offer substantial process improvements that have the potential to significantly improve process plant operations. Prediction of gas solid flow fields, in processes such as pneumatic transport lines, risers, fluidized bed reactors, hoppers and precipitators are crucial to the operation of most process plants. Up to now, the inability to accurately model these interactions has limited the role that simulation could play in improving operations. In recent years, computational fluid dynamics (CFD) software developers have focused on this area to develop new modeling methods that can simulate gas-liquid-solid flows to a much higher level of reliability. As a result, process industry engineers are beginning to utilize these methods to make major improvements by evaluating alternatives that would be, if not impossible, too expensive or time-consuming to trial on the plant floor. Over the past few decades, CFD has been used to improve process design by allowing engineers to simulate the performance of alternative configurations, eliminating guesswork that would normally be used to establish equipment geometry and process conditions. The use of CFD enables engineers to obtain solutions for problems with complex geometry and boundary conditions. A CFD analysis yields values for pressure, fluid velocity, temperature, and species or phase concentration on a computational grid throughout the solution domain.

The key advantages of CFD are:

1. It provides the flexibility to change design parameters without the expense of hardware changes. It therefore costs less than laboratory or field experiments, allowing engineers to try more alternative designs than would be feasible otherwise.

2. It has a faster turnaround time than experiments.

3. It guides the engineer to the root of problems, and is therefore well suited for trouble-shooting.

4. It provides comprehensive information about a flow field, especially in regions where measurements are either difficult or impossible to obtain.

CHAPTER 3

CFD MODELING OF THREE PHASE FLUIDIZED BED

Introduction to Modeling of Multiphase Flows

A large number of flows encountered in nature and technology are a mixture of phases. Physical phases of matter are gas, liquid and solid but the concept of phase in multiphase flow system is applied in a broader sense. In multiphase flow, a phase can be defined as an identifiable class of material that has a particular inertial response to and interaction with the flow and the potential field in which it is immersed. For example , different sized solid particles of the same material can be treated as different phases because each collection of particles wit the same material can be treated as different phases because each collection of particles with the same size will have a similar dynamical response to the flow field.

- ***Multiphase Flow Regimes***
- ***Examples of Multiphase Systems***
- ***Approach to Multiphase Modeling***
- ***Choosing a Multiphase Model***

3.1 MULTIPHASE FLOW REGIMES

Multiphase flow can be classified by the following regimes, grouped into four categories.

- Gas-liquid or liquid-liquid flows
  - Bubbly flow: discrete gaseous or fluid bubbles in a continuous fluid
  - Droplet flow: discrete fluid droplets in a continuous gas
  - Slug flow: large bubbles in a continuous fluid
  - Stratified / free-surface flow: immiscible fluids separated by clearly defined interface
- Gas solid flows
  - Particle laden flow: discrete solid particles in a continuous gas

- Pneumatic transport: flow pattern depends on factors such as solid loading, Reynolds number and particle properties. Typical patterns are dune flow , slug flow , packed beds and homogenous
- Fluidized beds: consist of a vertical cylinder containing particles where gas is introduced through a distributor. The has rising through the bed suspend the particles. Depending on the gas flow rate , bubbles appear and rise through the bed intensifying the mixing within the bed.

- Liquid solid flows
  - Slurry flow: transport of particles in liquids. The fundamental behavior of liquid solid flows varies with the properties of the solid particles relative to those of the liquid.
  - Hydro transport examples: mineral processing , biomedical and physiochemical fluid systems.
- Sedimentation examples: mineral processing
  - Is normally less than 1. when the Stokes number is larger than 1, the characteristic of the flow is liquid solid fluidization
  - Hydro transport: densely distributed solid particles in a continuous liquid
  - Sedimentation: a tall column initially containing a uniform dispersed mixture of particles. At the bottom the particles will slow down and form a sludge layer . at the top a clear interface will appear and in the middle a constant settling zone will exist.
- Three phase flows (combinations of the others listed above)

Each of these flow regimes is illustrated in Figure below.

3.2 Examples of Multiphase Systems

Specific examples of each regime are describe below

- Bubbly flow examples: absorbers, aeration , airlift pumps, cavitations , evaporators, flotation and scrubbers
- Droplet flow examples : absorbers , atomizers, combustors , cryogenic pumping, dryers, evaporation , gas cooling and scrubbers
- Slug flow examples: large bubble motion in pipes or tanks

- Stratified / free-surface flow examples: sloshing in offshore separator devices , boiling and condensation in nuclear reactors
- Particle laden flow examples: cyclone separators, air classifiers, dust collectors, and dust laden environmental flows.
- Pneumatic transport examples : transport of cement , grains and metal powders
- Fluidized bed examples: fluidized bed reactors, circulating fluidized beds, bio-reactors.

3.3 APPROACHES TO MULTIPHASE MODELING:

Advances in computational fluid mechanics have provided the basis for further insight into the dynamics of the multiphase flow. Currently there are two approaches for the numerical calculations of multiphase flows:

1. Euler-Lagrange approach
2. Euler-Euler approach

3.3.1 The Euler-Lagrange Approach:

The Lagrangian discrete phase model follows the Euler-Lagrange approach. The fluid phase is treated as a continuum by solving the time-averaged Navier-Stokes equations, while the dispersed phase is solved by tracking a large number of particles, bubbles, or droplets through the calculated flow field. The dispersed phase can exchange momentum, mass and energy with the fluid phase.

A fundamental assumption made in this model is that the dispersed second phase occupies a low volume fraction, even though high mass loading , $m_{particle} >= m_{fluid}$ is acceptable. The particle or droplet trajectories are computed individually at specified intervals during the fluid phase calculation. This makes the model appropriate for the modeling of spray dryers , coal and liquid fuel combustion , and some particle-laden flows, but inappropriate for the modeling of liquid-liquid mixtures, fluidized beds or any application where the volume fraction of the second phase is not negligible.

3.3.2 The Euler-Euler Approach

In the Euler-Euler approach the different phases are treated mathematically as interpenetrating continua. Since the volume of a phase can not be carried occupied by the other phases , the concept of the volume fraction is introduced. These volume fractions are assumed to be continuous functions of space and time and their sum is equal to one. Conservation equations for each phase are derived to obtain a set of equations , which have similar structure for all phases. These equations are closed by providing constitutive relations that are obtained from empirical information or in the case of granular flows by application of kinetic theory. There are three different Euler-Euler multiphase models available:

The volume of fluid (VOF) model,
The mixture model and
The Eulerian model.

3.3.2.1 The VOF Model:

The VOF model is a surface tracking technique applied to a fixed Eulerian mesh. It is designed foe two or more immiscible fluids where the position of the interface between the fluids is of interest. In the VOF model, a single set of momentum equations is shared by the fluids and the volume fraction of each of the fluids in each computational cell is tracked throughout the domain. The applications of VOF model include stratified flows, free surface flows, filling, sloshing, and the motion of large bubbles in a liquid, the motion of liquid after a dam break, the prediction of jet breakup (surface tension) and the steady or transient tracking of any liquid- gas interface.

3.3.2.2 The Mixture Model:

The mixture model is designed for two of more phases (fluid or particulate). As in the Eulerian model, the phases are treated as interpenetrating continua. The mixture model solves for the mixture momentum equation and prescribes relative velocities to describe the dispersed phase. Applications of the mixture model include particle-laden flows with low loading, bubbly flows, and sedimentation and cyclone separators. The mixture model can also be used without relative velocities for the dispersed phase to model homogenous multiphase flow.

3.3.2.3 The Eulerian Model:

The Eulerian model is the most complex of the multiphase models. It solves a set of n momentum and continuity equations for each phase. Couplings are achieved through the pressure and inter phase exchange coefficients. The manner in which this coupling is handled depends upon the type of phases involved; granular (fluid-solid) flows are handled differently than non-granular (fluid-fluid) flows. For granular flows, the properties are obtained from application of kinetic theory. Momentum exchange between the phases is also dependent upon the type of mixture being modeled. Applications of the Eulerian Multiphase Model include bubble columns, risers, particle suspension, and fluidized beds.

3.4 CHOOSING A MULTIPHASE MODEL

The first step in solving any multiphase problem is to determine which of the regimes best represent your flow. General guidelines provides some broad guidelines for determining the appropriate models for each regime, and detailed guidelines provides details about how to determine the degree of interphase coupling for flows involving bubbles , droplets or particles , and the appropriate models for different amounts of coupling.

Guidelines

In general, once that the flow regime is determined , the best representation for a multiphase system can be selected using appropriate model based on following guidelines. Additional details and guidelines for selecting the appropriate model for flows involving bubbles particles or droplets can be found.

- For bubble , droplet and particle-laden flows in which dispersed-phase volume fractions are less than or equal to 10% use the discrete phase model.
- For bubble, droplet and particle-laden flows in which the phases mix and / or dispersed phase volume fractions exceeed 10% , use either the mixture model. For slug flow , use the VOF model.
- For stratified / free-surface flows, use the VOF model.
- For pneumatic transport use the mixture model for homogenous flow or the Eulerian Model for granular flow.
- For fluidized bed , use the Eulerian Model for granular flow.
- For slurry flows and hydro transport, use Eulerian or Mixture model.
- For sedimentation, use Eulerian Model.

CHAPTER 4

EXPERIMENTAL SECTION

A schematic diagram of the experimental set up is shown in the figure: 1 The experiment has been conducted in Perspex glass column of 10 cm internal diameter, 125 cm in height, and 1cm thick. The pressure drop across the fluidized bed is measured by manometer using carbon tetrachloride as manometric fluid. A calming section is provided below the distributor plate for uniform distribution of air.

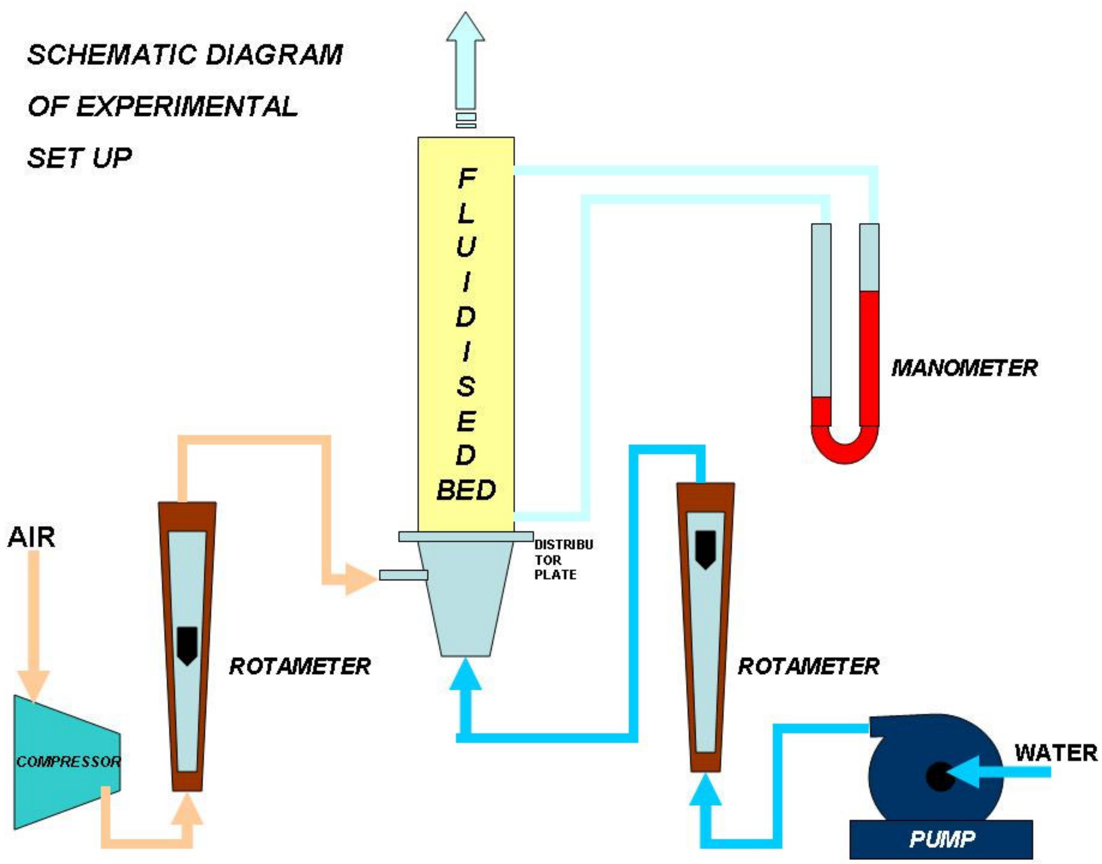


FIGURE- 4.1

4.1 EXPERIMENTAL SETUP-

The experimental set up consist broadly consists of the following parts.

1. Compressor
2. Receiver
3. Constant pressure tank
4. Rota meter
5. Fluidized bed
6. Calming section with glass beads
7. Distributor
8. Pressure tapings
9. Manometer
10. Conductivity probe
11. Digital Oscilloscope

Fluidized bed, which was taken here, is made of Perspex glass. Its geometrical shape is cylindrical as shown in figure-4.2. The dimensions of the fluidized bed are total height (vertical) 145cm ,Diameter (outer): 11cm,Diameter (inner): 10cm

At the bottom, we fix with a Perspex glass made cone shape set up as shown in the figure-4.3.In between the cone and the fluidized bed there are distributor plates which means for the uniform distribution of air and liquid in the column as shown in figure-4.4 and 4.5. A calming section is provided below the distributor plate for uniform distribution of air as shown in figure-4.6.Provisions are made at the top and bottom of the fluidized to keep the limbs of the manometer to monitor the pressure drop. Digital oscilloscope an electronic instrument which displays and records the electric signal. This instrument is really essential for gas holdup measurement.

***Solid particles*:**

The following different density and size solids were used

Solid Particle	*Size (mm)*	*Density (Kg/m3)*
Laterite	4.05	3313
Iron Ore	4.05	3994
Coal	4.05	1592
Dolomite	4.05	2652

Dolomite	3.075	2652

Liquid :

The following different viscosity and density liquids were used.

Liquids	Density(Kg/m3) at 35c	Viscosity(cp) at 35c
Water	995.6	1
24%(w/w) Glycerol sol.	1062.5	1.0482
18%(w/w) Glycerol sol.	1048.4	1.256
12%(w/w) Glycerol sol.	1035	1.119
6%(w/w) Glycerol sol.	1021.3	1.058

Fig-4.2-Column

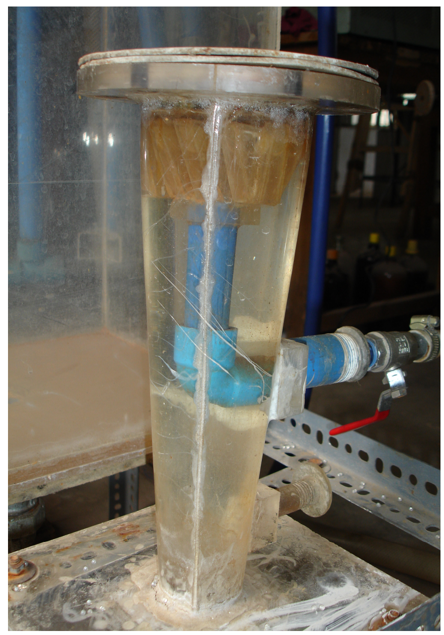


Fig-4.3-Column Bottom

Fig-4.4-Distributor Plate

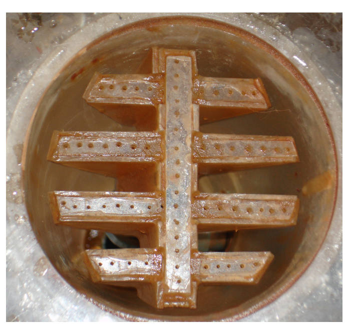


Fig-4.5-Sparger

Fig-4.6-Calming Section

4.2 EXPERIMENTAL PROCEDURE:

In the experimental work, it has been attempted to study the effect of static bed height, superficial gas velocity, density of bed material on the pressure drop, gas hold up with different sizes of bed particles.

The density of various bed materials is measured by volume displacement method. Different weights of bed materials are added into measuring cylinder and by the method mentioned above the densities are calculated.

The following procedure is adopted for the experiment.

1) Column is charged with solid particles (Laterite) to a height Hs.
2) The column is filled up with the liquid(water).
3) Compressed air is passed in to the column through the bottom of the bed using a control valve and rotameter.
4) Gradually the air flow rate is increased using the control valve starting from the 0 m^3/hr.
5) The changes of height, the pressure drop for every flow rate of air at constant liquid flow rate are noted down.
6) The same procedure is repeated by changing the liquid flow rate (using control valve and rotameter) and holding air flow rate constant.
7) All above procedures (1-5) are repeated for 3 other different bed materials(Iron ore, coal, Dolomite)

Now in the next part liquid of different viscosity is used to study its effect on pressure drop , bed height and gas hold up at different flow rates of air and liquid. The liquid selected here is glycerol. Dolomite is used as the bed material.

8) The column is filled up with 24% Glycerol solution.
9) Procedures 3-6 mentioned above are repeated for this solution.
10) Gas hold up at different height and radial position is measured with the help of an electric probe. Voltage supplied is 16 V. The readings are saved with the help of Digital Oscilloscope in either FTP or floppy disk in the form of Excel sheets.
11) The solution is diluted to 18%,12% and 6% and the procedures 8-10 are repeated.

4.3 PROCEDURE FOR CFD ANALYSIS USING FLUENT 6.1

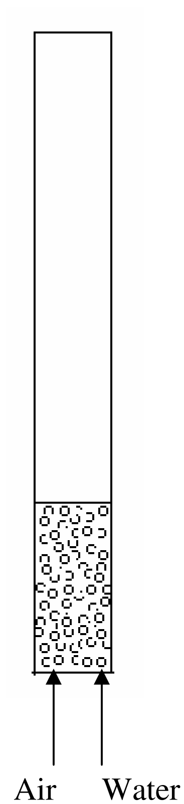
This procedure examines the flow of air, solids of uniform size and liquid in a fluidized bed. In this procedure we will explain how to:

- Use the Eulerian granular model
- Set boundary conditions
- Calculate a solution using the segregated solver
- Compare the results obtained with analytical results.

Problem Description:

The problem consists of a three phase fluidized bed in which air and liquid (water) flows through the bottom of the domain. The bed consists of solid material (Dolomite) of uniform which forms a desired height in the bed.

The figure is shown below.



Air:

Flow rate:24 lpm
Density:1.225 kg/m3
Viscosity:0.01789cp

Solid (Laterite):

Bed Static Height:17.6cm
Density:3313
Particle Size:4.05mm

Liquid(Water):

Flow rate:10
Density:995.6 kg/m3
Viscosity:1cp

Fig: Problem Specification **Operating Conditions (Sample)**

Procedure:

Start the 2D double-precision version of **FLUENT**

Step 1: Grid

1. Read the grid file fluid-bed mesh

   File→Read→Case

   As fluent reads the file the progress appears on the window

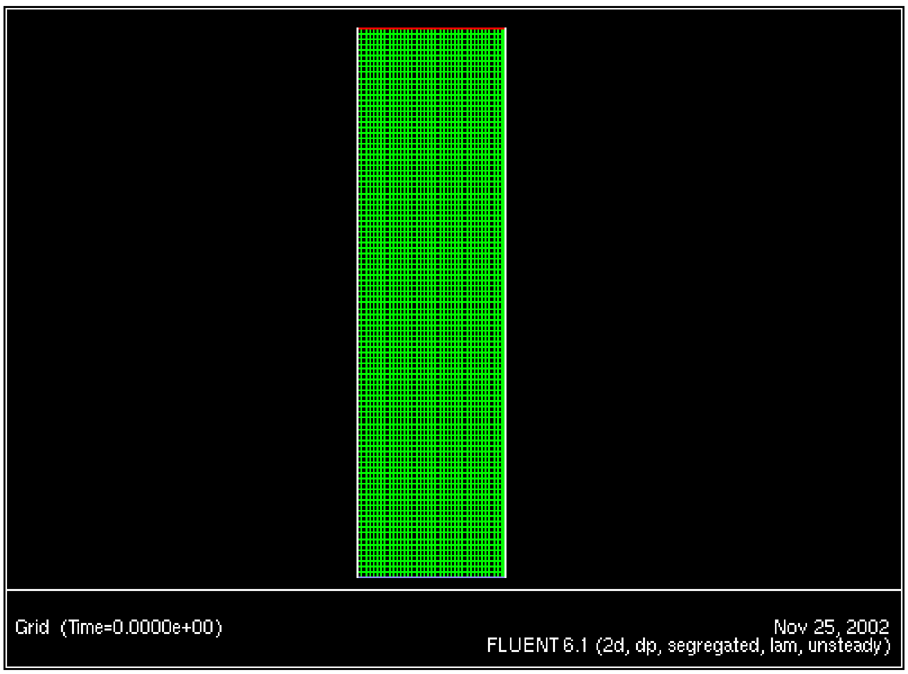
2. Check the grid.

   Grid→Check

   FLUENT will perform various checks on the mesh and will report the progress in the console window. Pay particular attention to the minimum reported volume. This should be always positive.

3. Display the grid.

   Display→Grid



Step 2: Models

1. Keep the default settings for the 2D segregated unsteady solver.

   The segregated solver must be used for multiphase calculations.

   Define →Models →Solver...

   (a)Under Time, select Unsteady.

2. Enable the Eulerian multiphase model with 3 phases.

   Define →Models →Multiphase...

   (a) Select **Eulerian** as the **Model**.

   (b) Select 3 in no. of phases

(c) Click ok

3. Set the gravitational acceleration.

Define →Operating Conditions...

(a) Turn on **Gravity**.

The panel will expand to show additional inputs.

(b) Set the **Gravitational Acceleration** in the **Y** direction to `-9.81` m/s ^{2}.

Step 3 : Materials

1. Define→Materials

The properties of air and water in the database of the fluent program can be modified by putting in the values on the panel that appears.

For defining the solid material following procedure is adopted.

* In the main window, select material type *fluid* and write the name of the material as *solids* or any name of your choice.
* Then enter the properties such as density and viscosity.
* Keep the *chemical formula* field blank. Click *change/create*.
* Click no to the dialog box that appears so that the overwriting over database material properties is eliminated

Step four: Phases

1. Define the solid, liquid and gas phase in the fluidized bed.

Define→Phase

(a) Specify liquid as the primary phase

Select phase 1 in the panel and click the set button.

In the primary phase panel , enter the phase name as Liquid.

Select water in the phase material dropdown list.

Click ok.

(b) Specify air as the secondary phase.

Select phase 2 in the panel and click the set button.

In the secondary phase panel, enter the phase name as air.

Select air in the phase material dropdown list. Click ok

(c) Specify solids as the secondary phase.

Select phase 3 in the panel and click the set button.

In the secondary phase panel, enter the phase name as solids.

Select solids in the phase material dropdown list. Click ok

2. Check the inter-phase interactions formulations to be used.

Click the **Interaction...** button in the **Phases** panel.

The following interactions are selected.

Liquid – Air: Syamlal Obrien

Solid-Liquid: Gidaspow

Solid-Air-Gidaspow

Step five: Boundary conditions

For this problem you need to set boundary conditions for all the boundaries.

Define→Boundary conditions

1. Set the conditions at ***v_inlet*** for the primary phase.

In the boundary conditions panel select **liquid** in the **Phase** dropdown list and click **Set**.Keep the default velocity specifications and reference frames.

Set the velocity magnitude to 0.021 m/s.

Set the temperature to 35^0C.Click ok.

2. Set the conditions at ***v_inlet*** for the secondary phase solids.

In the **Boundary Conditions** panel, select **solids** from the **Phase** drop-down list and click **Set.**Keep the default velocity specifications and reference frames.

Set the velocity magnitude to 0 m/s.

Set the temperature to 35^0C.Keep the default value 0 for volume fraction.

3. Set the conditions at ***v_inlet*** for the secondary phase air.

In the **Boundary Conditions** panel, select **air** from the **Phase** drop-down list and click **Set.**Keep the default velocity specifications and reference frames.

Set the velocity magnitude to 0.051 m/s.

Set the temperature to 35^0C.

4. Set the boundary conditions for ***pressure outlet***

(a) Set the conditions poutlet for the mixture.

i. In the **Boundary Conditions** panel, select **mixture** in the **Phase** drop-down list and click **Set...**.

ii. Keep the default value of 0 for the **Gauge Pressure**. Click **OK**.

(b) Set the conditions poutlet for air.

In the **Boundary Conditions** panel, select **air** from the **Phase** drop-down list and click **Set.**

Set the backflow temperature to the temp. mentioned above.

(c) Set the conditions poutlet for solids.

In the **Boundary Conditions** panel, select **solids** from the **Phase** drop-down list and click **Set..**

Set the **Backflow Total Temperature** to `293`.

Set the **Backflow Granular Temperature** to `0.0001`.

Set the **Backflow Volume Fraction** to `0`.

Click **OK**.

(d) Set the conditions poutlet for primary phase liquid.

In the **Boundary Conditions** panel, select **liquid** from the **Phase** drop-down list and click **Set.**

Keep the default values and click OK.

5. Set the boundary conditions for **wall.**

Set specified shear as X=0 and Y=0 for all the phases.

Step six: Solution

Set the solution parameters.

1. Solve →Controls →Solution.

(a) Set the under-relaxation factor for **Pressure** to `0.3`.

(b) Set the under-relaxation factor for **Momentum** to `0.2`.

(c) Set the under-relaxation factor for **Volume Fraction** to `0.5`.

(d) Keep all default **Discretization** schemes.

(e) Click **OK**.

2. Enable the plotting of residuals during the calculation.

Solve →Monitors →Residual...

3. Initialize the solution.

Solve →Initialize →Initialize

Enter the initial velocities and the volume fraction in the panel that appears.

4. Define an adaptation register for the lower half of the fluidized bed.

Adapt→Region.

(a) Under **Input Coordinates**, specify the **Xmaximum** value as `0.5` **,`Xminimum as -0.5`** and the **Ymaximum** value as `0.3`.

(b) Click **Mark**.

(c) Click **Manage...**

*The **Manage Adaption Registers** panel will open.*

(d) Under **Registers**, in the **Manage Adaption Registers** panel, select **hexahedron-r0**, and click **Display**

5. Patch the initial volume fraction of solids in the lower half of the fluidized bed.

Solve →Initialize →Patch..

(a) In the **Phase** drop-down list, select **solids**.

(b) In the **Variable** drop-down list, select **Volume Fraction**.

(c) In the **Value** field, enter **0.598**.

(d) In the **Registers to Patch** list, select **hexahedron-r0**.

(e) Click **Patch**.

6. Display the contours of solids.

Display →Contours

7. Write the case file in the working directory.

File→Write→Case

8. Iterate the solution.

Set a time step size of 0.5 s and 7000 time steps.

9. Now make the settings for autosaving the results.

File→Write→Autosave

In the autosave data frequency enter 10.

10. Iterate the solution. **Solve→Iterate.**

The data files will get stored automatically in the working directory which can be read at any time with the help of previously saved case file.

The same procedure is repeated for other velocities of liquid and air, different bed materials and different liquid concentrations or viscosities.

CHAPTER 5

EXPERIMENTAL OBSERVATIONS

5.1 FLUIDIZATION USING DIFFERENT DENSITY BED MATERIALS

Bed Material- Laterite (Size-4.05mm ,Density-3313kg/m3)

Table-5.1- Two phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	H-ccl$_4$	Press drop
0	0	0	0	0.175	0.175	1	50.8	0
5	0	0.010616	0	0.175	0.175	1	50.5	94.176
10	0	0.021231	0	0.175	0.175	1	49.8	313.92
14	0	0.029724	0	0.175	0.175	1	49.4	439.488
18	0	0.038217	0	0.175	0.175	1	48.8	627.84
22	0	0.046709	0	0.175	0.175	1	48	878.976
26	0	0.055202	0	0.175	0.175	1	47.2	1130.112
30	0	0.063694	0	0.175	0.175	1	46.5	1349.856
34	0	0.072187	0	0.175	0.185	1.057143	46.5	1349.856
38	0	0.080679	0	0.175	0.193	1.102857	46.6	1318.464
45	0	0.095541	0	0.175	0.219	1.251429	46.2	1444.032
52	0	0.110403	0	0.175	0.238	1.36	45.7	1600.992
60	0	0.127389	0	0.175	0.279	1.594286	45.3	1726.56
70	0	0.14862	0	0.175	0.329	1.88	44.7	1914.912
80	0	0.169851	0	0.175	0.415	2.371429	43	2448.576

Table-5.2 Three phase fluidization

QL	QG	U-Liq	U-Gas	Hs	H	H/Hs	H-ccl4	Press drop
0	24	0	0.050955	0.175	0.164	0.937143	54.9	0
5	24	0.010616	0.050955	0.175	0.159	0.908571	53.5	439.488
10	24	0.021231	0.050955	0.175	0.145	0.828571	51.2	1161.504
14	24	0.029724	0.050955	0.175	0.145	0.828571	50.5	1381.248
18	24	0.038217	0.050955	0.175	0.153	0.874286	50.4	1412.64
25	24	0.053079	0.050955	0.175	0.167	0.954286	50.2	1475.424
35	24	0.07431	0.050955	0.175	0.205	1.171429	50	1538.208
45	24	0.095541	0.050955	0.175	0.255	1.457143	50.3	1444.032
55	24	0.116773	0.050955	0.175	0.33	1.885714	49.2	1789.344
65	24	0.138004	0.050955	0.175	0.42	2.4	42	4049.568
30	0	0.063694	0	0.175	0.175	1	0.002	
30	12	0.063694	0.025478	0.175	0.175	1	0.003	
30	18	0.063694	0.038217	0.175	0.175	1	0.005	
30	24	0.063694	0.050955	0.175	0.184	1.051429	0.006	
30	30	0.063694	0.063694	0.175	0.19	1.085714	0.008	
30	36	0.063694	0.076433	0.175	0.195	1.114286	0.015	
30	42	0.063694	0.089172	0.175	0.197	1.125714	0.02	
30	48	0.063694	0.101911	0.175	0.214	1.222857	0.03	
30	60	0.063694	0.127389	0.175	0.214	1.222857	0.04	

Bed Material- Iron Ore (Size-4.05mm ,Density-3993kg/m3)

Table-5.3- Two phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	H-ccl_4	Press Drop
0	0	0	0	0.175	0.175	1	50.3	0
10	0	0.021231	0	0.175	0.175	1	49.3	313.92
15	0	0.031847	0	0.175	0.175	1	48.8	470.88
20	0	0.042463	0	0.175	0.175	1	47.8	784.8
25	0	0.053079	0	0.175	0.175	1	47	1035.936
30	0	0.063694	0	0.175	0.175	1	45.9	1381.248
35	0	0.07431	0	0.175	0.18	1.028571	46.5	1192.896
40	0	0.084926	0	0.175	0.195	1.114286	46.2	1287.072
45	0	0.095541	0	0.175	0.215	1.228571	46	1349.856
50	0	0.106157	0	0.175	0.235	1.342857	45.8	1412.64
55	0	0.116773	0	0.175	0.27	1.542857	45.5	1506.816
60	0	0.127389	0	0.175	0.285	1.628571	45.5	1506.816
65	0	0.138004	0	0.175	0.3	1.714286	45.5	1506.816
70	0	0.14862	0	0.175	0.315	1.8	45.5	1506.816

Table-5.4-Three phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	H-ccl_4	Pressure drop
0	24	0	0.050955	0.175	0.165	0.942857	53.6	0
10	24	0.021231	0.050955	0.175	0.155	0.885714	51	816.192
15	24	0.031847	0.050955	0.175	0.15	0.857143	49.9	1161.504
20	24	0.042463	0.050955	0.175	0.155	0.885714	49.6	1255.68
25	24	0.053079	0.050955	0.175	0.17	0.971429	49.6	1255.68
30	24	0.063694	0.050955	0.175	0.18	1.028571	49.7	1224.288
35	24	0.07431	0.050955	0.175	0.2	1.142857	49.7	1224.288
40	24	0.084926	0.050955	0.175	0.22	1.257143	49.6	1255.68
45	24	0.095541	0.050955	0.175	0.235	1.342857	49.7	1224.288
50	24	0.106157	0.050955	0.175	0.28	1.6	49.7	1224.288
55	24	0.116773	0.050955	0.175	0.325	1.857143	49.9	1161.504
60	24	0.127389	0.050955	0.175	0.355	2.028571	49.9	1161.504
65	24	0.138004	0.050955	0.175	0.395	2.257143	49.9	1161.504
35	0	0.07431	0	0.175	0.18	1.028571		
35	12	0.07431	0.025478	0.175	0.185	1.057143	0.005	
35	24	0.07431	0.050955	0.175	0.195	1.114286	0.01	
35	36	0.07431	0.076433	0.175	0.215	1.228571	0.02	
35	48	0.07431	0.101911	0.175	0.225	1.285714	0.04	
35	60	0.07431	0.127389	0.175	0.215	1.228571	0.06	

Bed Material- Coal (Size-4.05mm ,Density-1592.5kg/m3)

Table-5.5- Two phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	H-ccl_4	Pressure Drop
0	0	0	0	0.175	0.175	1	50.3	0
2	0	0.004246	0	0.175	0.175	1	50.2	31.392
4	0	0.008493	0	0.175	0.175	1	50.1	62.784
6	0	0.012739	0	0.175	0.175	1	50	94.176
8	0	0.016985	0	0.175	0.18	1.028571	49.8	156.96
10	0	0.021231	0	0.175	0.195	1.114286	49.5	251.136
12	0	0.025478	0	0.175	0.205	1.171429	49.4	282.528
14	0	0.029724	0	0.175	0.22	1.257143	49.3	313.92
16	0	0.03397	0	0.175	0.235	1.342857	49.3	313.92
20	0	0.042463	0	0.175	0.285	1.628571	49.3	313.92
25	0	0.053079	0	0.175	0.4	2.285714	49.2	345.312
30	0	0.063694	0	0.175	0.6	3.428571	49.2	345.312

Table-5.6-Three phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	H-ccl_4	Pressure Drop
0	24	0	0.050955	0.175	0.175	1	54.6	0
2	24	0.004246	0.050955	0.175	0.175	1	54.2	125.568
4	24	0.008493	0.050955	0.175	0.18	1.028571	54	188.352
6	24	0.012739	0.050955	0.175	0.185	1.057143	53.7	282.528
8	24	0.016985	0.050955	0.175	0.19	1.085714	53.4	376.704
10	24	0.021231	0.050955	0.175	0.2	1.142857	53.2	439.488
12	24	0.025478	0.050955	0.175	0.24	1.371429	53.1	470.88
14	24	0.029724	0.050955	0.175	0.29	1.657143	53.1	470.88
16	24	0.03397	0.050955	0.175	0.35	2	53	502.272
18	24	0.038217	0.050955	0.175	0.43	2.457143	53	502.272
20	24	0.042463	0.050955	0.175	0.52	2.971429	53	502.272
14	6	0.029724	0.012739	0.175	0.18	1.028571		
14	12	0.029724	0.025478	0.175	0.22	1.257143		
14	18	0.029724	0.038217	0.175	0.27	1.542857		
14	24	0.029724	0.050955	0.175	0.33	1.885714		
14	30	0.029724	0.063694	0.175	0.38	2.171429		
14	36	0.029724	0.076433	0.175	0.44	2.514286		

Bed Material- Dolomite (Size-4.05mm, Density-2652kg/m3)

Table-5.7- Two phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	H-ccl_4	Pressure Drop
0	0	0	0	0.175	0.175	1	37.3	0
5	0	0.010616	0	0.175	0.175	1	37	94.176
10	0	0.021231	0	0.175	0.175	1	36.3	313.92
15	0	0.031847	0	0.175	0.175	1	35.7	502.272
20	0	0.042463	0	0.175	0.175	1	34.8	784.8

22	0	0.046709	0	0.175	0.175	1	34.3	941.76
25	0	0.053079	0	0.175	0.179	1.022857	34.3	941.76
30	0	0.063694	0	0.175	0.191	1.091429	34.3	941.76
35	0	0.07431	0	0.175	0.206	1.177143	34.3	941.76
40	0	0.084926	0	0.175	0.216	1.234286	34.1	1004.544
45	0	0.095541	0	0.175	0.246	1.405714	33.9	1067.328
50	0	0.106157	0	0.175	0.276	1.577143	33.8	1098.72
55	0	0.116773	0	0.175	0.291	1.662857	33.8	1098.72

Table-5.8-Three phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	H-ccl$_4$	Pressure drop
2	24	0.004246	0.050955	0.175	0.158	0.902857	40.4	0
5	24	0.010616	0.050955	0.175	0.153	0.874286	39.4	313.92
7.5	24	0.015924	0.050955	0.175	0.15	0.857143	38.3	659.232
10	24	0.021231	0.050955	0.175	0.15	0.857143	37.9	784.8
12	24	0.025478	0.050955	0.175	0.15	0.857143	37.9	784.8
4	24	0.008493	0.050955	0.175	0.152	0.868571	37.8	816.192
16	24	0.03397	0.050955	0.175	0.155	0.885714	37.7	847.584
20	24	0.042463	0.050955	0.175	0.16	0.914286	37.5	910.368
25	24	0.053079	0.050955	0.175	0.175	1	37.5	910.368
30	24	0.063694	0.050955	0.175	0.195	1.114286	37.4	941.76
35	24	0.07431	0.050955	0.175	0.235	1.342857	37.5	910.368
40	24	0.084926	0.050955	0.175	0.27	1.542857	37.8	816.192
45	24	0.095541	0.050955	0.175	0.306	1.748571	38	753.408
50	24	0.106157	0.050955	0.175	0.376	2.148571	36.7	1161.504

5.2 FLUIDIZATION USING DIFFERENT VISCOSITY FLUIDS

Liquid-24%(w/w)Glycerol solution(Density-1062.5kg/m^3 ,Viscosity-1.482cp)

Table-5.9- Two phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	HCCl4	Press Drop
0	0	0	0	21.6	21.6	1	47.7	0
5	0	0.010616	0	21.6	21.6	1	47.6	31.392
10	0	0.021231	0	21.6	21.6	1	45.9	565.056
12	0	0.025478	0	21.6	21.6	1	45.3	753.408
14	0	0.029724	0	21.6	21.6	1	44.8	910.368
16	0	0.03397	0	21.6	21.6	1	44.2	1098.72
18	0	0.038217	0	21.6	22	1.018519	44.5	1004.544
20	0	0.042463	0	21.6	22.6	1.046296	44.5	1004.544
25	0	0.053079	0	21.6	23.6	1.092593	44.4	1035.936
30	0	0.063694	0	21.6	25	1.157407	44.3	1067.328
35	0	0.07431	0	21.6	27.5	1.273148	44.2	1098.72
40	0	0.084926	0	21.6	29.5	1.365741	44.2	1098.72
45	0	0.095541	0	21.6	35	1.62037	44.2	1098.72
50	0	0.106157	0	21.6	42.5	1.967593	44.2	1098.72

60	0	0.127389	0	21.6	60	2.777778	44.2	1098.72

Table-5.10-Three phase fluidization.

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	HCCl4	Press Drop	Gas Holdup
0	24	0	0.050955	21.6	20.6	0.953704	50.4	0	
2	24	0.004246	0.050955	21.6	19.6	0.907407	50.3	31.392	
6	24	0.012739	0.050955	21.6	20	0.925926	49.9	156.96	0.271
10	24	0.021231	0.050955	21.6	21.6	1	49.3	345.312	0.2304
12	24	0.025478	0.050955	21.6	23.5	1.087963	49.2	376.704	0.2184
15	24	0.031847	0.050955	21.6	24.5	1.134259	49	439.488	0.1984
20	24	0.042463	0.050955	21.6	26.5	1.226852	48.9	470.88	0.18
25	24	0.053079	0.050955	21.6	30	1.388889	48.5	596.448	0.1782
30	24	0.063694	0.050955	21.6	34.5	1.597222	48.5	596.448	0.1641
35	24	0.07431	0.050955	21.6	40.5	1.875	48.5	596.448	0.1538
40	24	0.084926	0.050955	21.6	45	2.083333	48.7	533.664	0.151
18	0	0.038217	0	21.6	21.6	1			0
18	6	0.038217	0.012739	21.6	22	1.018519	0.5		0.1689
18	12	0.038217	0.025478	21.6	23	1.064815	0.7		0.1684
18	18	0.038217	0.038217	21.6	25	1.157407	1		0.1914
18	24	0.038217	0.050955	21.6	27	1.25	3		0.1810
18	30	0.038217	0.063694	21.6	30	1.388889	5		0.208
18	36	0.038217	0.076433	21.6	33	1.527778	6.5		0.1812

Liquid-18%(w/w)Glycerol solution(Density-1048.4kg/m^3 ,Viscosity-1.256cp)

Table-5.11- Two phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	HCCl4	Press Drop
0	0	0	0	21.6	21.6	1	47.5	0
3	0	0.006369	0	21.6	21.6	1	47.1	125.568
6	0	0.012739	0	21.6	21.6	1	46.7	251.136
10	0	0.021231	0	21.6	21.6	1	45.3	690.624
12	0	0.025478	0	21.6	21.6	1	45	784.8
14	0	0.029724	0	21.6	21.6	1	44.5	941.76
16	0	0.03397	0	21.6	21.6	1	44.2	1035.936
18	0	0.038217	0	21.6	21.6	1	44.1	1067.328
19	0	0.04034	0	21.6	21.7	1.00463	44	1098.72
20	0	0.042463	0	21.6	22.6	1.046296	44	1098.72
25	0	0.053079	0	21.6	23.6	1.092593	44	1098.72
30	0	0.063694	0	21.6	25	1.157407	43.9	1130.112
35	0	0.07431	0	21.6	29	1.342593	43.8	1161.504
40	0	0.084926	0	21.6	30.5	1.412037	43.8	1161.504
45	0	0.095541	0	21.6	32	1.481481	43.8	1161.504
50	0	0.106157	0	21.6	44	2.037037	43.8	1161.504
60	0	0.127389	0	21.6	58	2.685185	43.8	1161.504

Table-5.12-Three phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	HCCl4	Press Drop	Gas Holdup
0	24	0	0.050955	21.6	20.6	0.953704	53.2	0	
3	24	0.006369	0.050955	21.6	19.6	0.907407	49.9	1035.936	0.2712
6	24	0.012739	0.050955	21.6	20	0.925926	49.7	1098.72	0.2641
10	24	0.021231	0.050955	21.6	21.6	1	49.2	1255.68	0.2248
12	24	0.025478	0.050955	21.6	22.6	1.046296	49.2	1255.68	0.255
15	24	0.031847	0.050955	21.6	23.5	1.087963	49.2	1255.68	0.2446
20	24	0.042463	0.050955	21.6	25	1.157407	48.9	1349.856	0.2466
25	24	0.053079	0.050955	21.6	28	1.296296	48.6	1444.032	0.2243
30	24	0.063694	0.050955	21.6	34	1.574074	48.5	1475.424	0.2223
35	24	0.07431	0.050955	21.6	39	1.805556	48.5	1475.424	0.2074
40	24	0.084926	0.050955	21.6	47	2.175926	49	1318.464	0.1960
19	6	0.04034	0.012739	21.6	22	1.018519			0.1537
19	12	0.04034	0.025478	21.6	22.5	1.041667			0.1680
19	18	0.04034	0.038217	21.6	24.5	1.134259			0.2018
19	24	0.04034	0.050955	21.6	26.5	1.226852			0.2185
19	30	0.04034	0.063694	21.6	28.5	1.319444			0.2273
19	36	0.04034	0.076433	21.6	21	0.972222			0.2184
19	42	0.04034	0.089172	21.6	33	1.527778			0.2242

Liquid-12%(w/w)Glycerol solution(Density-1035kg/m^3 ,Viscosity-1.118cp)

Table-5.13- Two phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	HCCl4	Press Drop
0	0	0	0	21.6	21.6	1	47.3	0
5	0	0.010616	0	21.6	21.6	1	46.6	219.744
10	0	0.021231	0	21.6	21.6	1	45.2	659.232
15	0	0.031847	0	21.6	21.6	1	44.3	941.76
17	0	0.036093	0	21.6	21.6	1	43.6	1161.504
19	0	0.04034	0	21.6	22	1.018519	43.8	1098.72
20	0	0.042463	0	21.6	23	1.064815	43.8	1098.72
25	0	0.053079	0	21.6	23.5	1.087963	43.8	1098.72
30	0	0.063694	0	21.6	26	1.203704	43.7	1130.112
35	0	0.07431	0	21.6	28	1.296296	43.7	1130.112
40	0	0.084926	0	21.6	33	1.527778	43.6	1161.504
45	0	0.095541	0	21.6	35.5	1.643519	43.5	1192.896
50	0	0.106157	0	21.6	38.5	1.782407	43.5	1192.896

Table-5.14- Three phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	HCCl4	Press Drop	
0	24	0	0.050955	21.6	20.5	0.949074	51.6	0	
3	24	0.006369	0.050955	21.6	19.5	0.902778	49.2	753.408	
6	24	0.012739	0.050955	21.6	20.5	0.949074	49	816.192	
10	24	0.021231	0.050955	21.6	21.6	1	48.6	941.76	0.2604
12	24	0.025478	0.050955	21.6	22.5	1.041667	48.6	941.76	0.259
15	24	0.031847	0.050955	21.6	23.5	1.087963	48.5	973.152	0.2472

20	24	0.042463	0.050955	21.6	27.5	1.273148	48.3	1035.936	0.2466
25	24	0.053079	0.050955	21.6	33	1.527778	48	1130.112	0.2280
30	24	0.063694	0.050955	21.6	36.5	1.689815	48	1130.112	0.2223
35	24	0.07431	0.050955	21.6	42.5	1.967593	48	1130.112	0.2100
40	24	0.084926	0.050955	21.6	48.5	2.24537	48.2	1067.328	0.2086
19	6	0.04034	0.012739	21.6	21.6	1			0.1374
19	12	0.04034	0.025478	21.6	22.5	1.041667			0.1643
19	18	0.04034	0.038217	21.6	24	1.111111			0.1734
19	24	0.04034	0.050955	21.6	28	1.296296			0.1744
19	30	0.04034	0.063694	21.6	30.5	1.412037			0.2033
19	36	0.04034	0.076433	21.6	33.5	1.550926			0.2184

Liquid-06%(w/w)Glycerol solution(Density-1021.3kg/m^3 ,Viscosity-1.058cp)

Table-5.15- Two phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	HCCl4	Press Drop
0	0	0	0	21.6	21.6	1	50.9	0
5	0	0.010616	0	21.6	21.6	1	50.2	219.744
10	0	0.021231	0	21.6	21.6	1	48.9	627.84
15	0	0.031847	0	21.6	21.6	1	47	1224.288
17	0	0.036093	0	21.6	21.6	1	47.4	1098.72
19	0	0.04034	0	21.6	21.6	1	47	1224.288
20	0	0.042463	0	21.6	21.8	1.009259	47	1224.288
25	0	0.053079	0	21.6	22.6	1.046296	47	1224.288
30	0	0.063694	0	21.6	24	1.111111	47	1224.288
35	0	0.07431	0	21.6	26.5	1.226852	47	1224.288
40	0	0.084926	0	21.6	32.5	1.50463	47	1224.288
45	0	0.095541	0	21.6	38	1.759259	47	1224.288
50	0	0.106157	0	21.6	41	1.898148	47	1224.288
55	0	0.116773	0	21.6	47	2.175926	47	1224.288

Table-5.16- Three phase fluidization

Q_L	Q_G	U_L	U_G	Hs	H	H/Hs	HCCl4	Press Drop	Gas Holdup
0	24	0	0.050955	21.6	19.6	0.907407	55.4	0	
3	24	0.006369	0.050955	21.6	19.6	0.907407	52.8	816.192	0.271
6	24	0.012739	0.050955	21.6	19.6	0.907407	52	1067.328	0.2304
10	24	0.021231	0.050955	21.6	21.6	1	51.6	1192.896	0.2184
15	24	0.031847	0.050955	21.6	22.6	1.046296	51.6	1192.896	0.2546
20	24	0.042463	0.050955	21.6	23.5	1.087963	51.6	1192.896	0.2527
25	24	0.053079	0.050955	21.6	25	1.157407	51.5	1224.288	0.2529
30	24	0.063694	0.050955	21.6	28	1.296296	51.5	1224.288	0.222
35	24	0.07431	0.050955	21.6	35.5	1.643519	51.5	1224.288	0.1838
40	24	0.084926	0.050955	21.6	42	1.944444	52	1067.328	0.1850
19.5	6	0.041401	0.012739	21.6	22.6	1.046296			0.1210
19.5	12	0.041401	0.025478	21.6	23.9	1.106481			0.1531

19.5	18	0.041401	0.038217	21.6	24.5	1.134259			0.1586
19.5	24	0.041401	0.050955	21.6	25.5	1.180556			0.1810
19.5	30	0.041401	0.063694	21.6	25.5	1.180556			0.208
19.5	36	0.041401	0.076433	21.6	25.5	1.180556			0.2012

Liquid-Water (Density-995.6kg/m^3 ,Viscosity-1.003cp)

Table-5.17 Gas Hold up

QL	QG	UL	UG	Gas Hold Up
20	6	0.0425	0.0127	0.1002
20	12	0.0425	0.0255	0.1051
20	18	0.0425	0.0382	0.1169
20	24	0.0425	0.051	0.12642
20	30	0.0425	0.0637	0.13214
20	36	0.0425	0.0764	0.13421
20	48	0.0425	0.1019	0.13752
15	24	0.0318	0.051	0.14728
25	24	0.0531	0.051	0.1259
30	24	0.0637	0.051	0.1118
36	24	0.0764	0.051	0.1069
48	24	0.1019	0.051	0.1023

5.3 PLOTS FOR FLUIDIZATION USING DIFFERENT DENSITY BED MATERIALS

TWO PHASE –

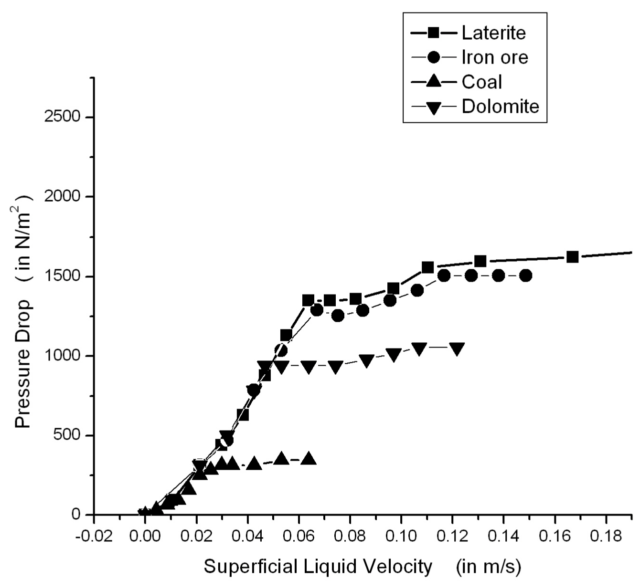


Fig. 5.1 Variation of pressure drop with respect to superficial liquid velocity for different bed materials

It can be grasped from the graph that with increase in particle density the minimum fluidization velocity increases. The pressure drop is higher for bed with higher density bed material. The pressure drop becomes constant after minimum fluidization velocity.

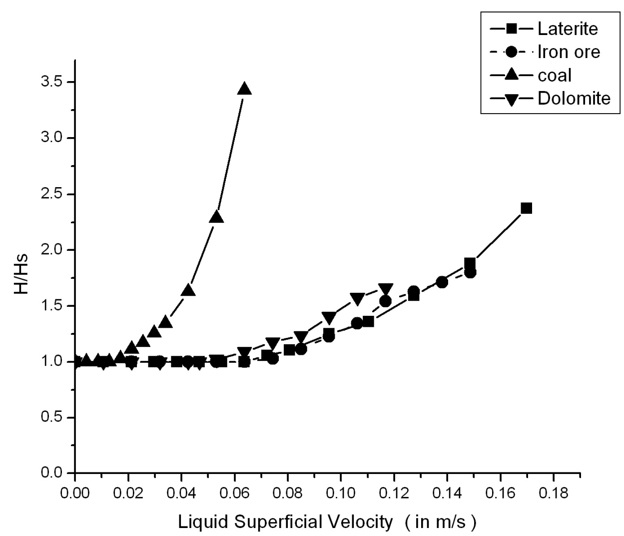


Fig.5.2 Variation of H/H_s with respect to liquid superficial velocity

For same liquid superficial velocity, the expansion ratio H/H_s increases with decrease in particle density. Also for same expansion ration the superficial velocity increases with increase in density of material.

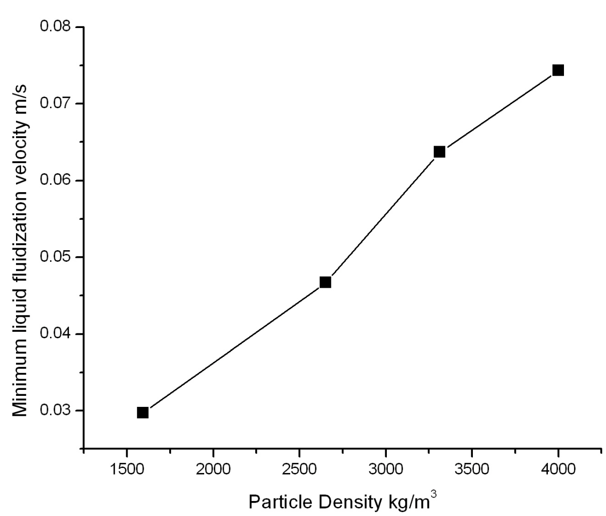


Fig. 5.3 Variation of minimum liquid fluidization velocity w.r.t. particle density

The minimum liquid fluidization velocity increases with increase in particle density.

THREE PHASE –

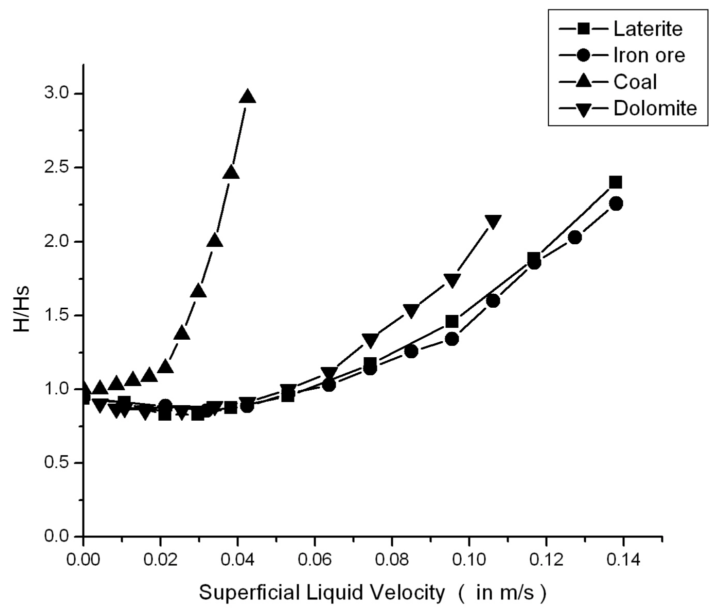


Fig.5.4 Variation of expansion ratio with respect to superficial liquid velocity

The bed expansion ratio is low for low density bed material. Bed expansion is a strong function of liquid superficial velocity for a particular bed material.

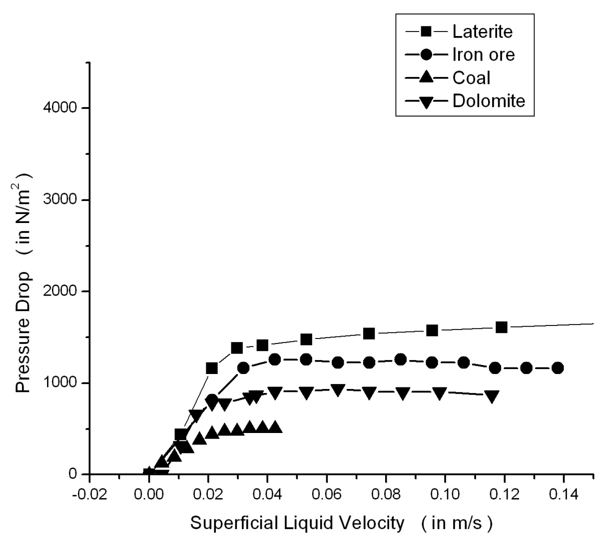


Fig. 5.5 Variation of pressure drop with respect to superficial liquid velocity

Pressure drop is not a strong function of liquid superficial velocity.

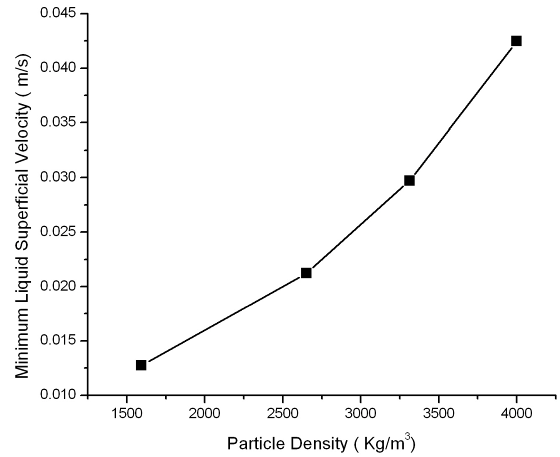


Fig. 5.6 Effect of particle density on minimum liquid fluidization velocity

Particle density is a strong function of minimum fluidization velocity as evident from the graph.

5.4 PLOTS FOR FLUIDIZATION USING DIFFERENT VISCOSITY FLUIDS

TWO PHASE –

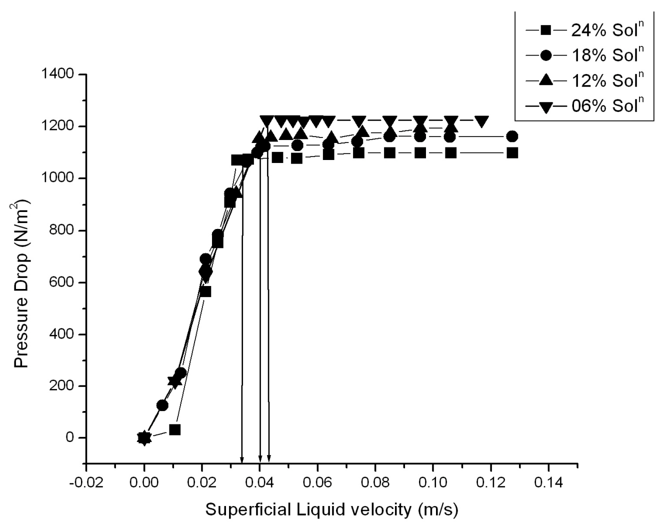


Fig. 5.7 Variation of pressure drop with respect to superficial liquid velocity for liquids of different viscosity

With increase in liquid viscosity and density the pressure drop decreases. At the same time minimum fluidization velocity increases with decrease in liquid viscosity.

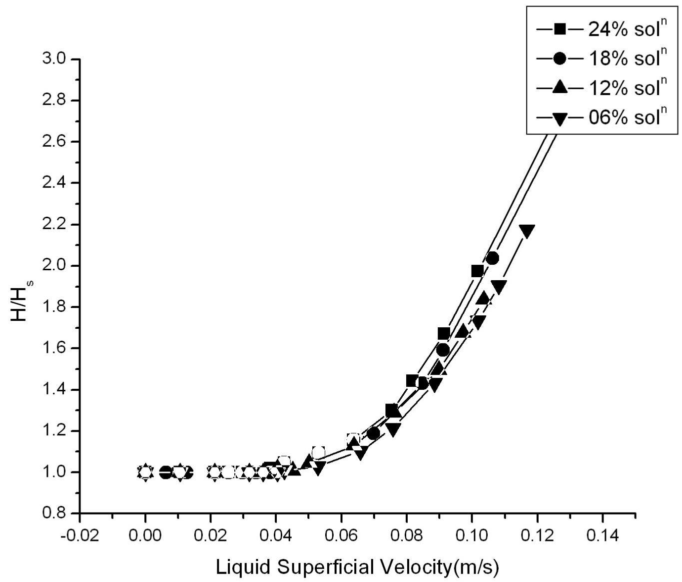


Fig.5.8 Variation of bed expansion ratio with respect to liquid superficial velocity for liquids of different viscosity

For same liquid superficial velocity, the expansion ratio $H/H_{s\ \text{increases}}$ with increase in liquid viscosity. Also for same expansion ratio the liquid superficial velocity increases with decrease in liquid viscosity.

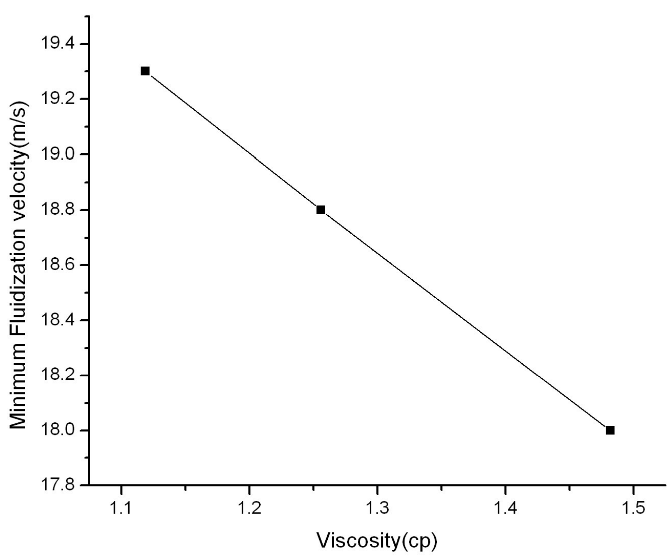


Fig.5.9 Effect of liquid viscosity on minimum liquid fluidization velocity

The minimum liquid fluidization velocity decreases with increase in viscosity.

THREE PHASE

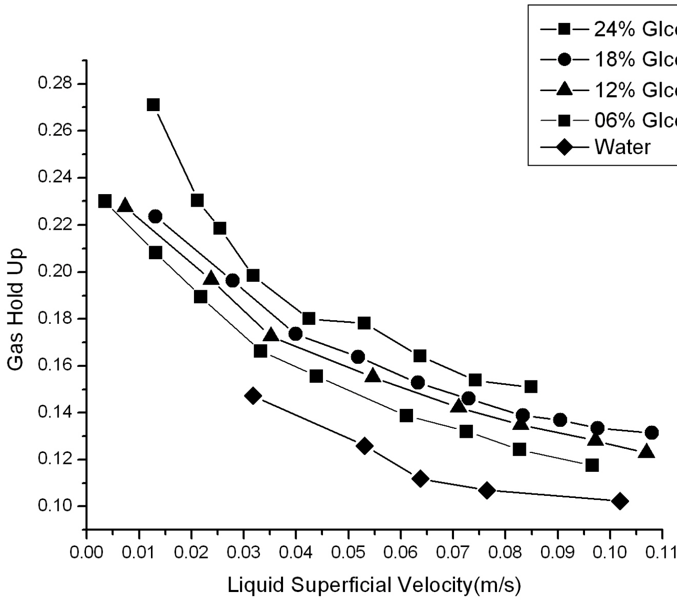


Fig.5.10 Variation of gas hold up with respect to liquid superficial velocity for liquids of different viscosity.

Gas hold up decreases with increase in liquid superficial velocity.

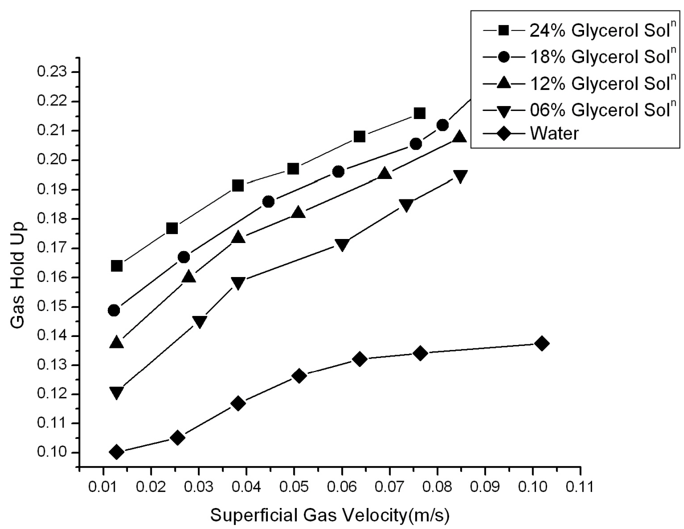


Fig.5.11 Effect of superficial gas velocity on gas hold up for liquids of different viscosity

The gas hold up is higher for higher viscosity fluid. It is low for water and increases as the viscosity increases. Hence it is strong function of liquid viscosity.

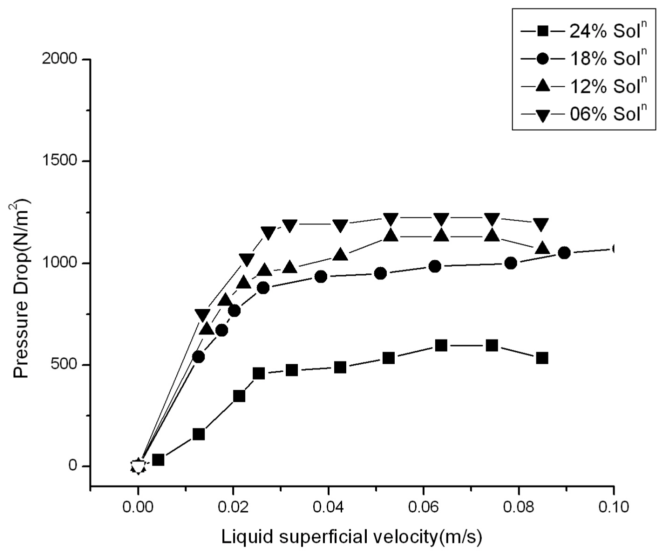


Fig.5.12 Variation of pressure drop with respect to liquid superficial velocity for liquids of different viscosity

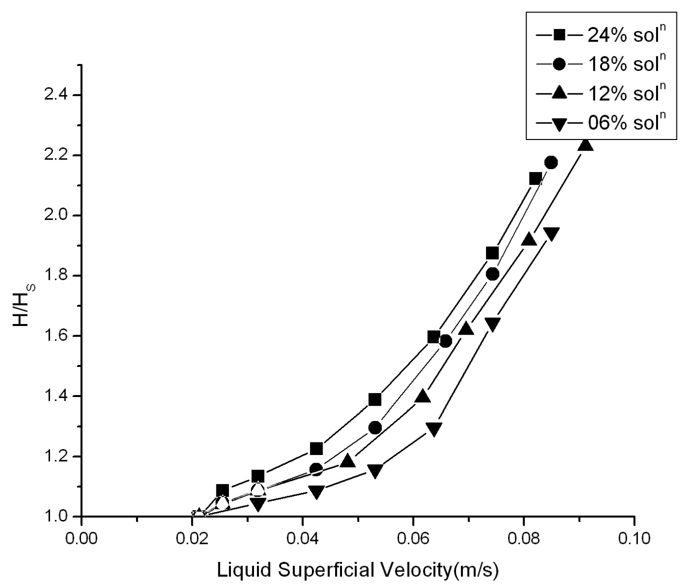


Fig 5.13 Variation of bed expansion ratio with respect to liquid superficial velocity

The bed expansion ratio is higher for higher viscosity fluid and it is a strong function of liquid superficial velocity though effect of changing the viscosity didn't have much effect on expansion ratio.

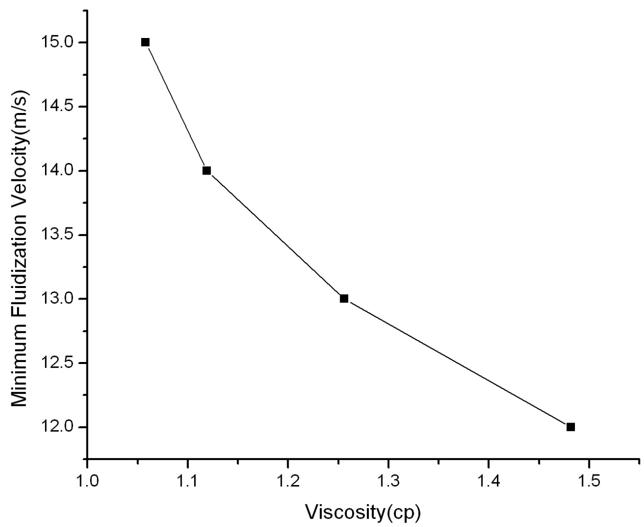


Fig.5.14 Effect of viscosity on liquid minimum fluidization velocity

From the above plots it is apparent that the pressure drop is influenced by the intial static bed height , bed expansion , particle size and density as well as the viscosity of the fluidizing medium.

CHAPTER 6

CFD RESULTS

CFD RESULTS Chapter-6

This section summarizes the results obtained with the help of Fluent software. The procedure followed for obtaining the results is already mentioned in chapter 4.

The results consists of CFD diagrams which pictures the contours of solid , liquid and gas volume fraction , absolute pressure of the mixture and magnitude of velocity vector of solid particles along the length of the column.
The following results are shown.

- Two phase fluidization with different bed materials
- Three phase fluidization with different bed materials
- Two phase fluidization with liquids of different viscosity
- Three phase fluidization with liquids of different viscosity

Two-phase laterite 0.02m/s liquid-velocity-

Contours of Solid Volume fraction

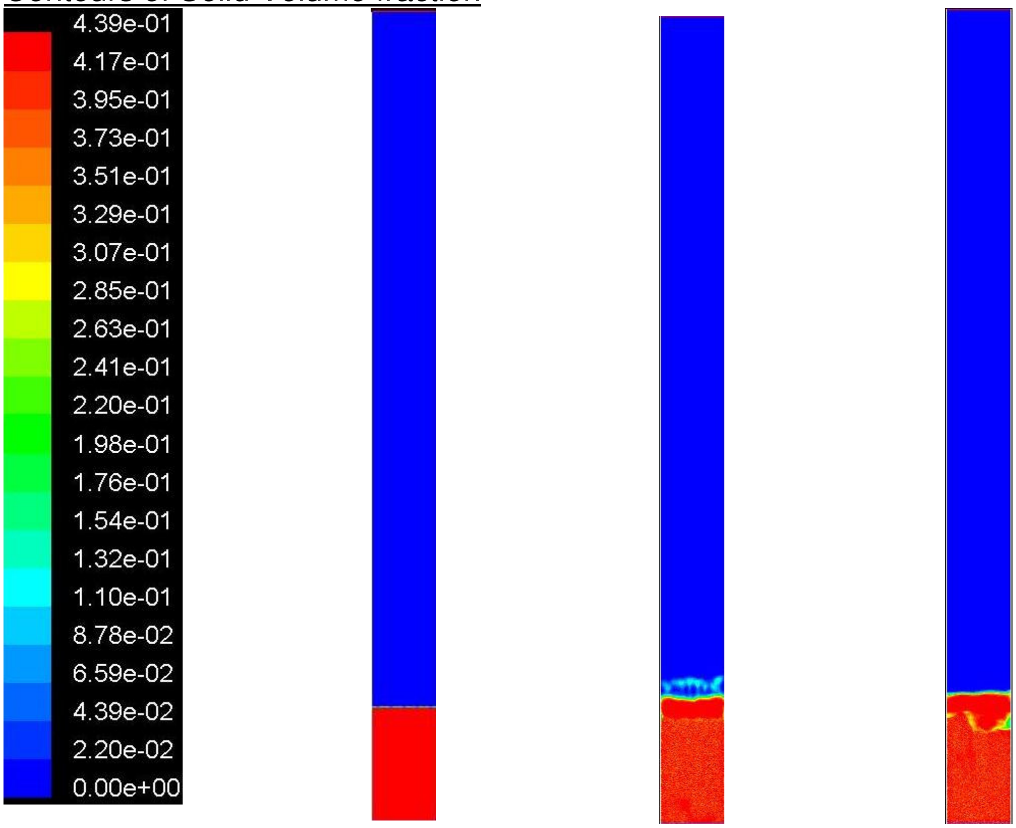


Figure-6.1 t = 0 sec t = 0.2 sec t = 0.8 sec

Contours of Liquid Volume fraction

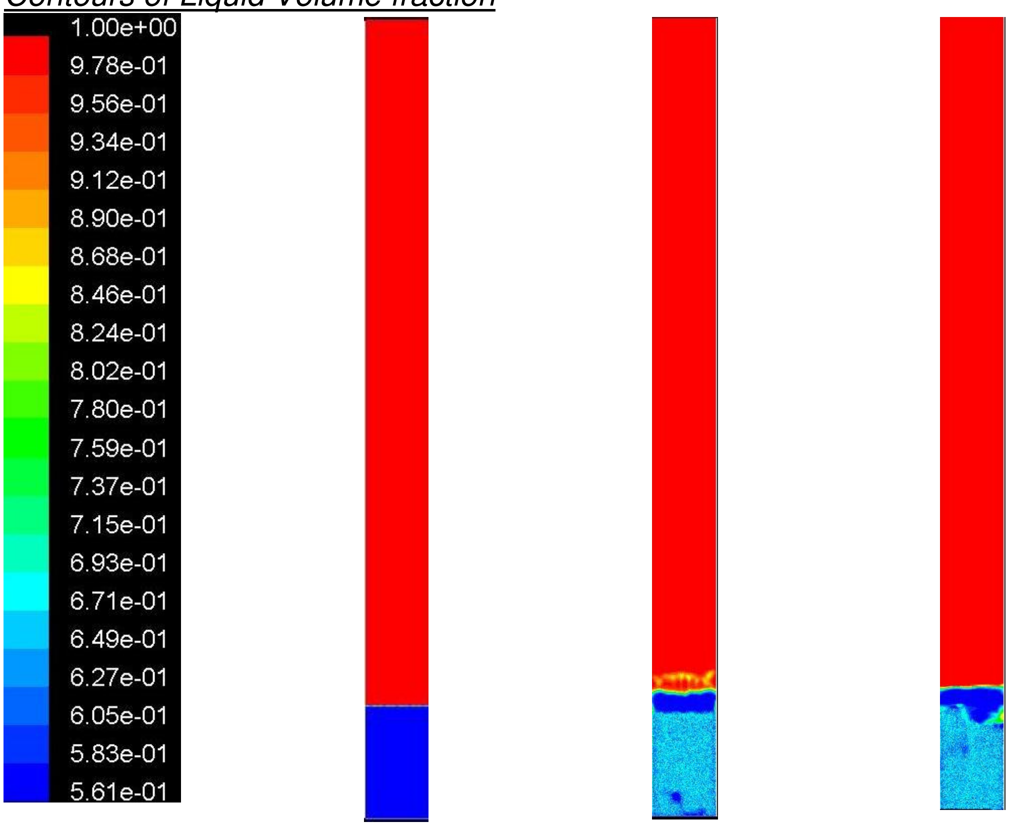


Figure-6.2 t = 0 sec t = 0.2 sec t = 0.8 sec

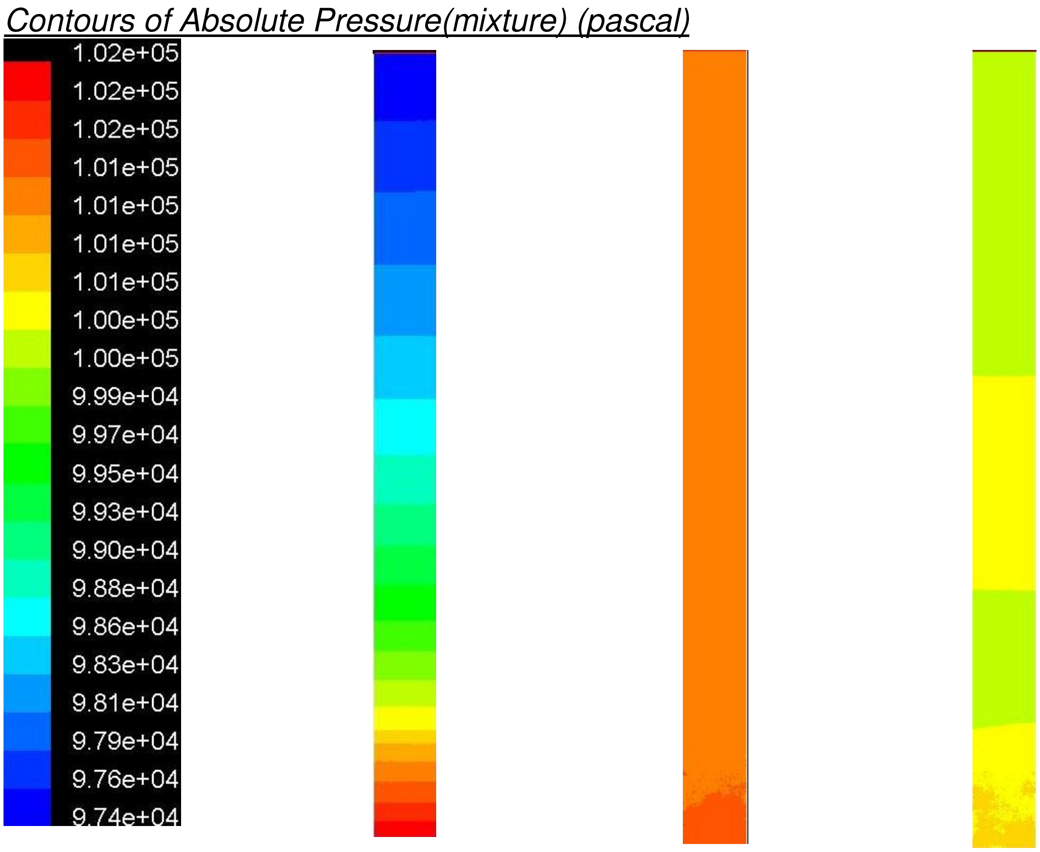


Figure-6.3 t = 0 sec t = 0.2 sec t = 0.8 sec

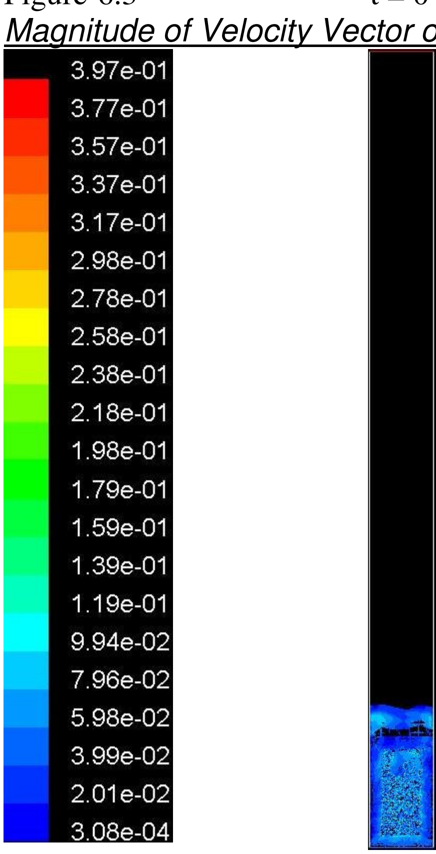


Figure-6.4 t = 0.8 sec

Two phase laterite 0.07m/s Liquid Velocity-

Contours of Solid fraction

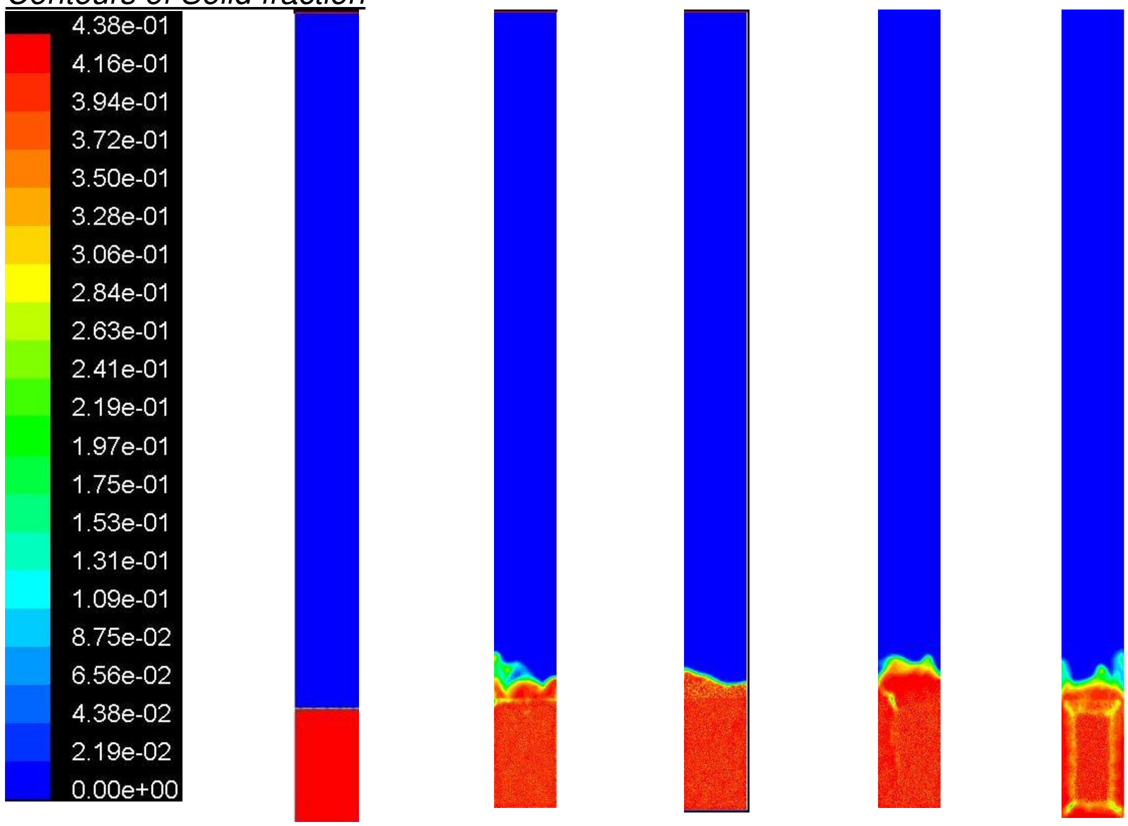


Figure-6.5 t=0sec t=0.4sec t=0.6sec t=0.8sec t=1sec

Contours of Liquid volume fraction

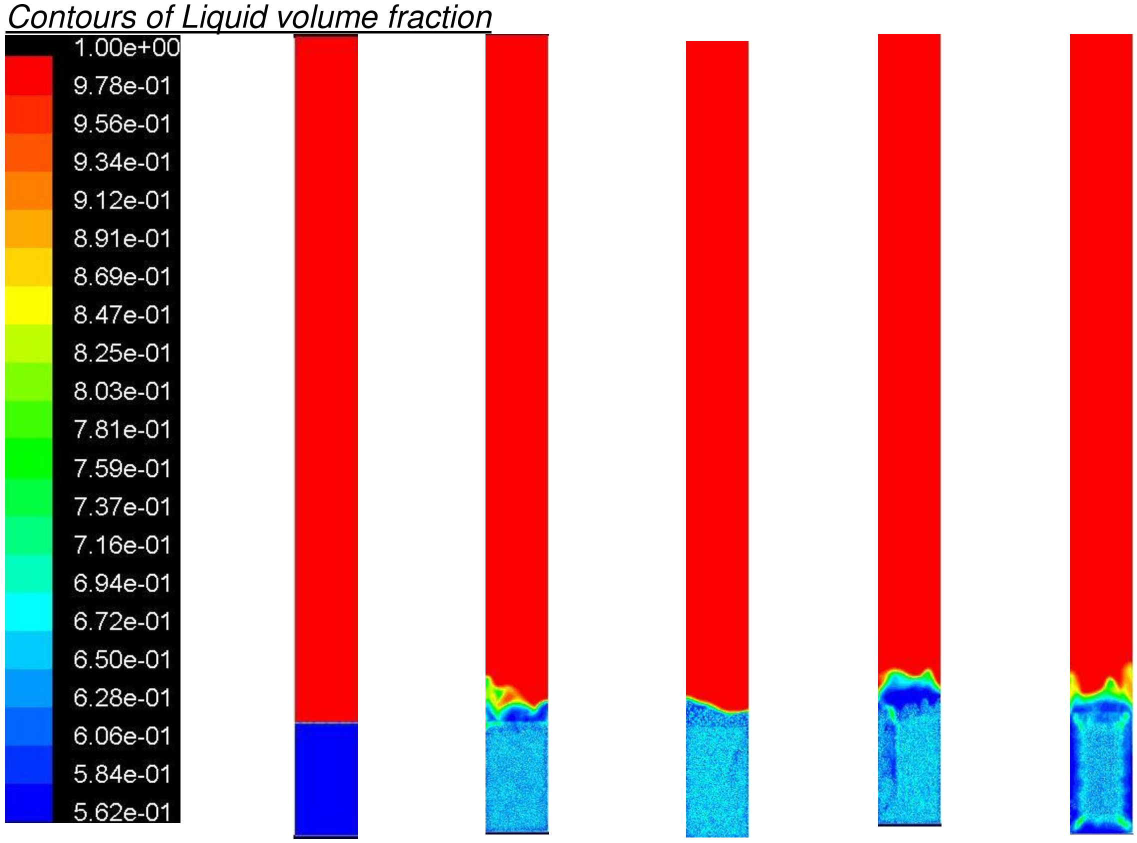


Figure-6.6 t=0sec t=0.4sec t=0.6sec t=0.8sec t=1sec

Contours of Absolute Pressure (mixture) (Pascal)

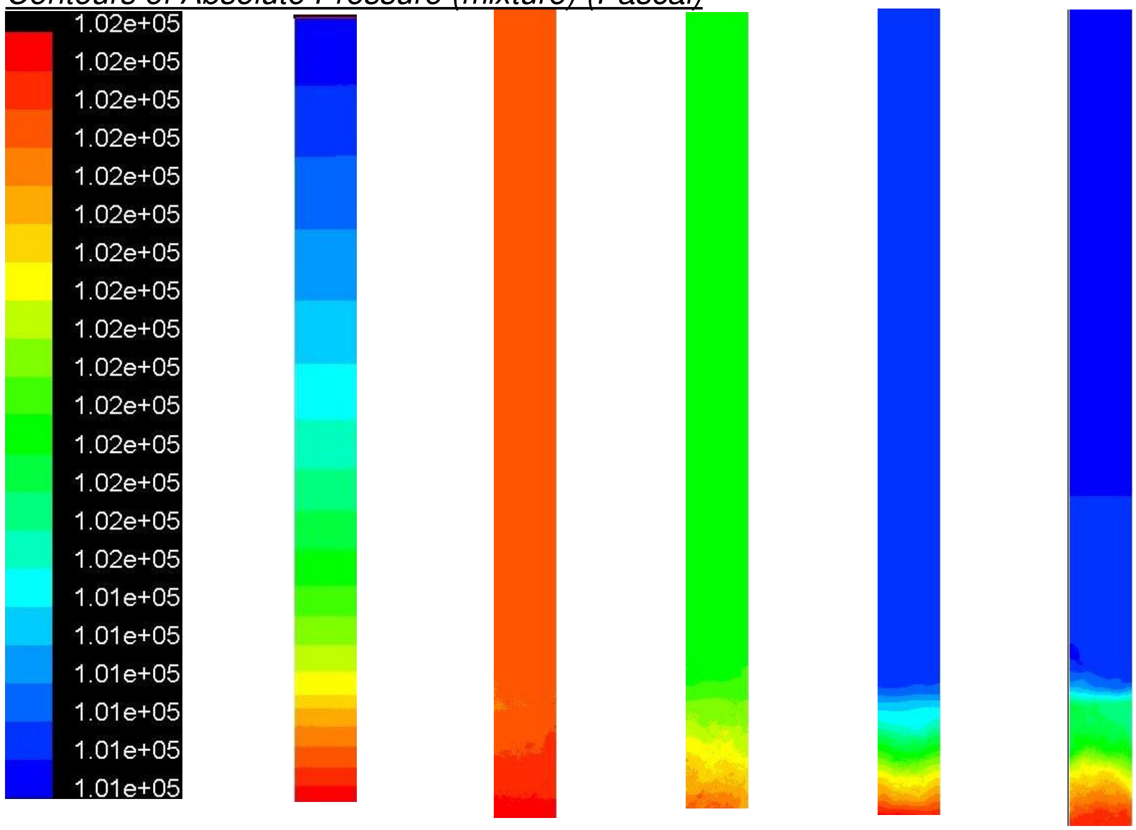


Figure-6.7 t=0sec t=0.4sec t=0.6sec t=0.8sec t=1sec

Magnitude of Velocity Vector of Solids

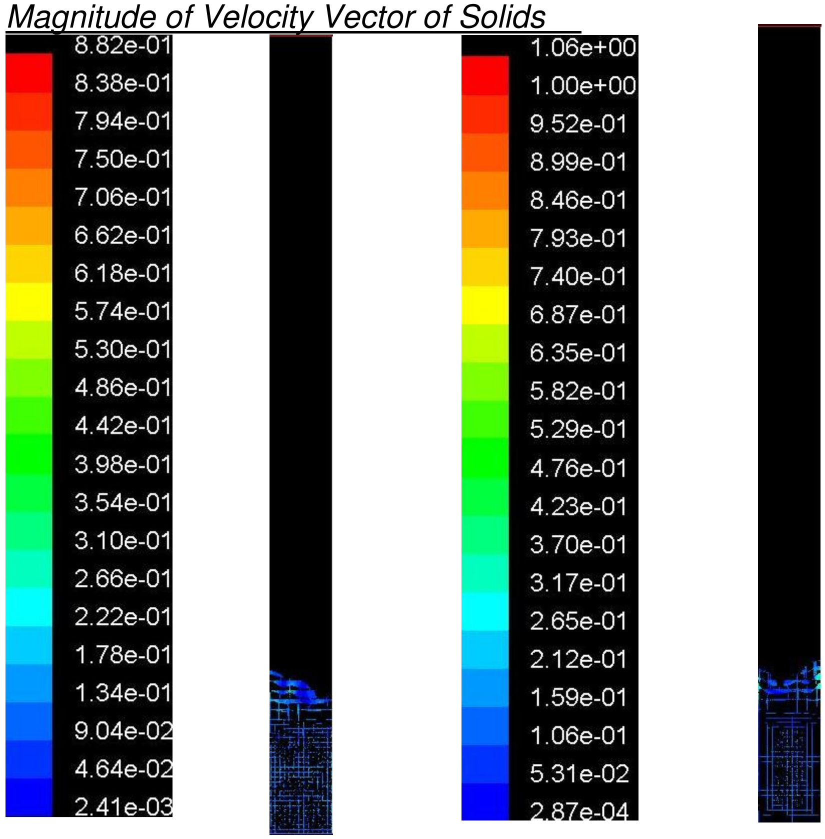


Figure-6.8 t = 0.8 sec t = 1sec

Two phase laterite 0.127m/s Liquid Velocity-

Contours of Solid fraction

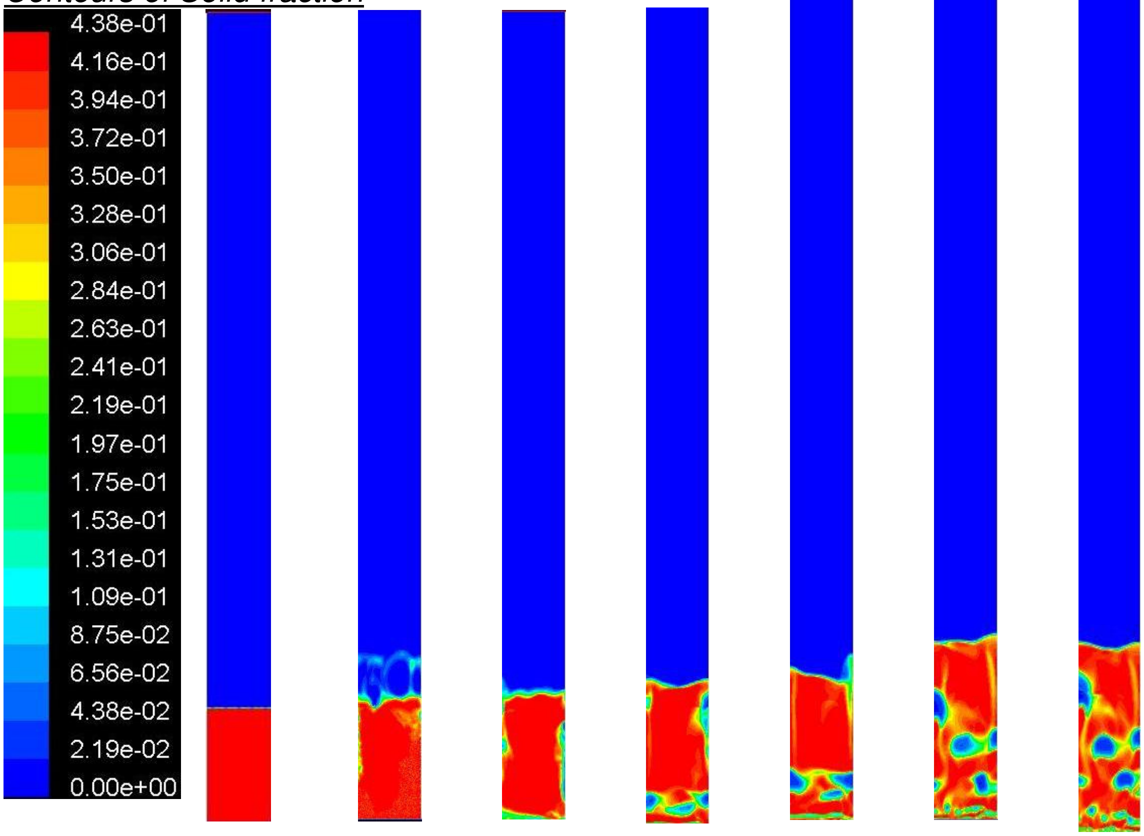


Figure-6.9 t=0s t=0.2s t=0.5s t=0.9s t=1.2s t=1.9s t=2.1s

Contours of Liquid volume fraction

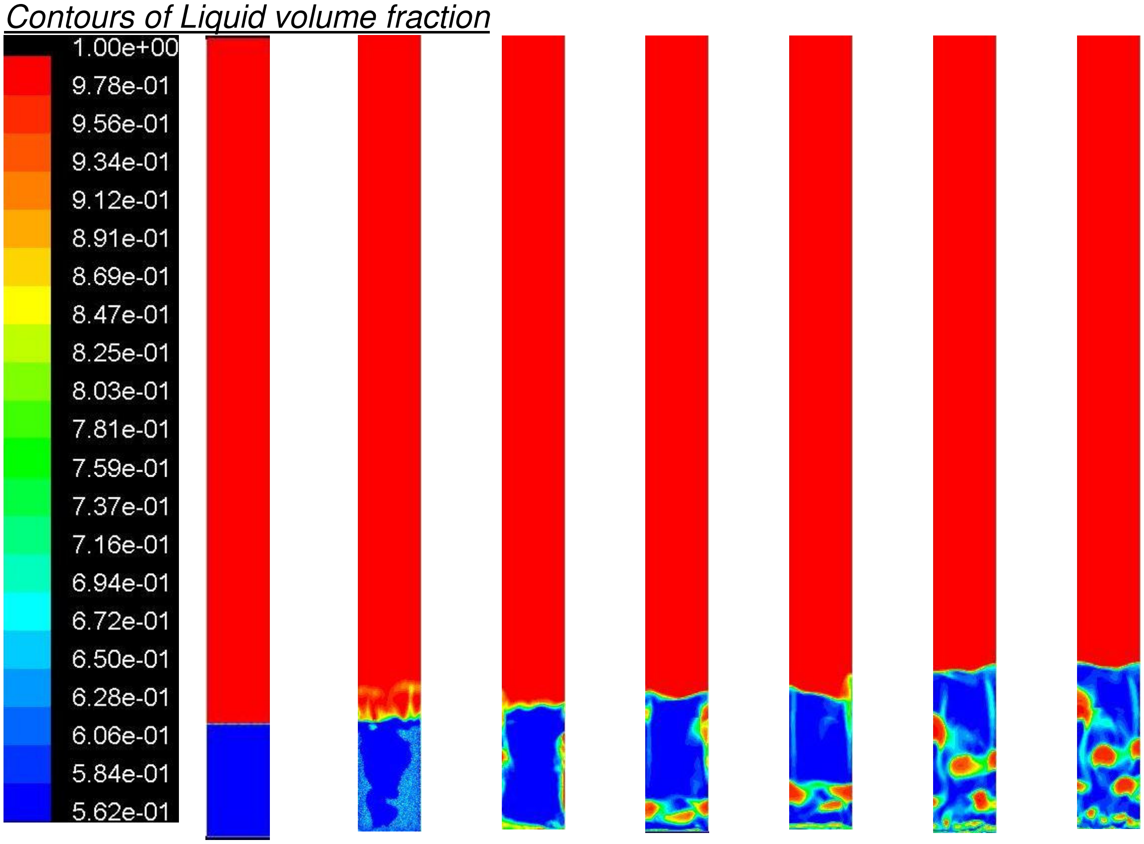


Figure-6.10 t=0s t=0.2s t=0.5s t=0.9s t=1.2s t=1.9s t=2.1s

Contours of Absolute Pressure (mixture) (Pascal)

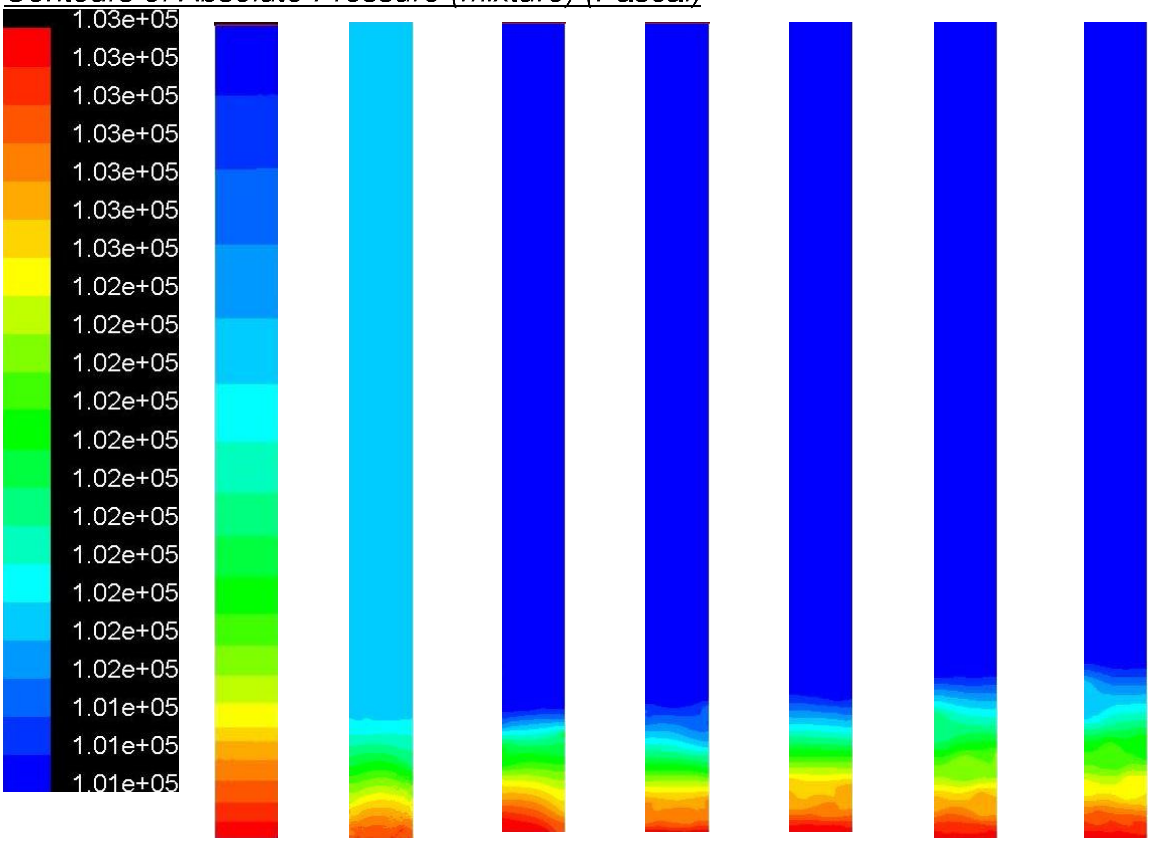


Figure-6.11 t=0s t=0.2s t=0.5s t=0.9s t=1.2s t=1.9s t=2.1s

Magnitude of Velocity Vector of Solids

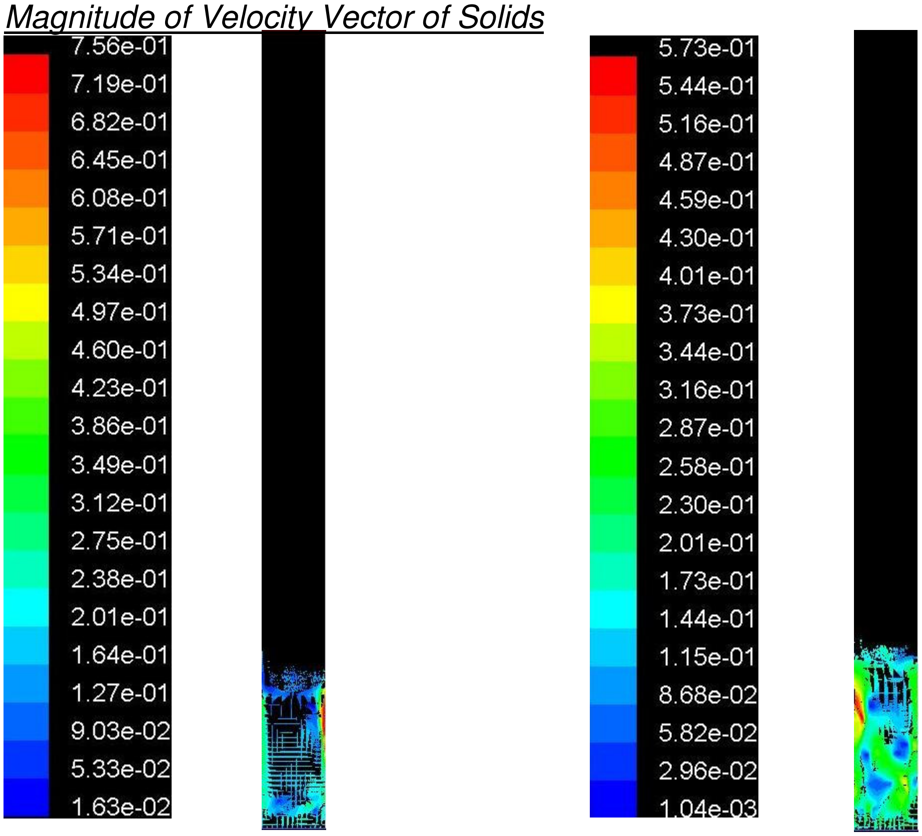


Figure-6.12 t=1sec t= 2sec

Two-phase Iron-ore 0.025m/s liquid-velocity-

Contours of Solid Volume fraction

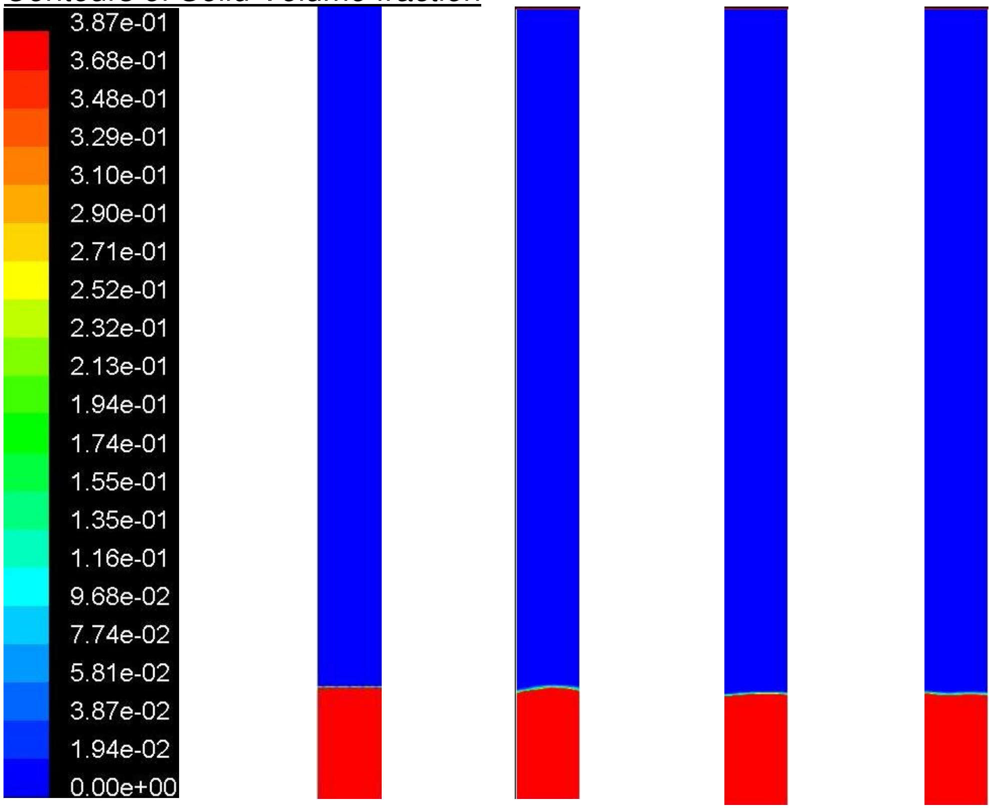


Figure-6.13 t=0sec t=1sec t=1.2sec t=1.5sec

Contours of Liquid Volume fraction

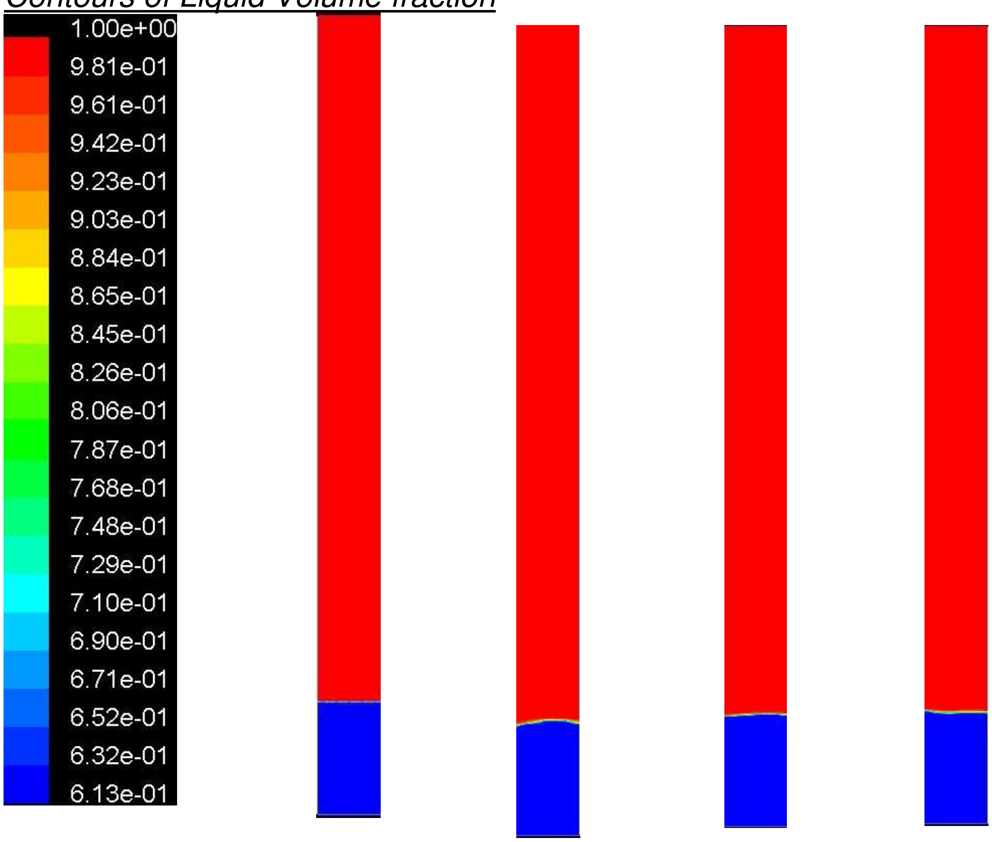


Figure-6.14 t=0sec t=1sec t=1.2sec t=1.5sec

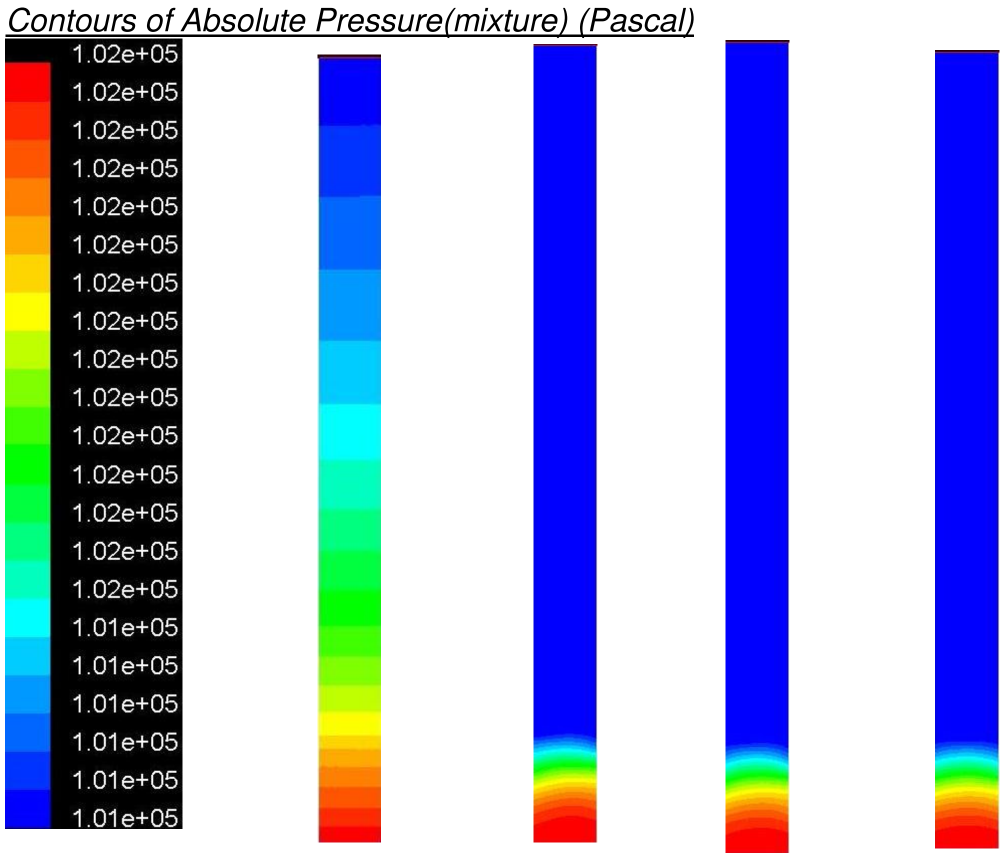


Figure-6.15 t=0sec t=1sec t=1.2sec t=1.5sec

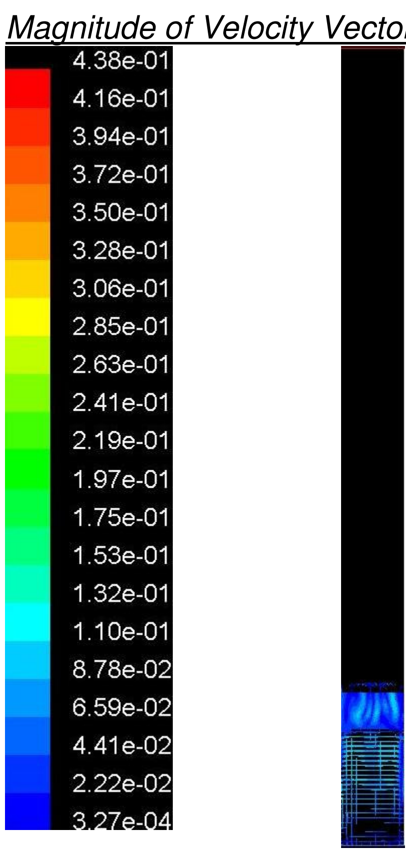


Figure-6.16 t=1.5sec

Two-phase Iron-ore 0.07m/s liquid-velocity-

Contours of Solid Volume fraction

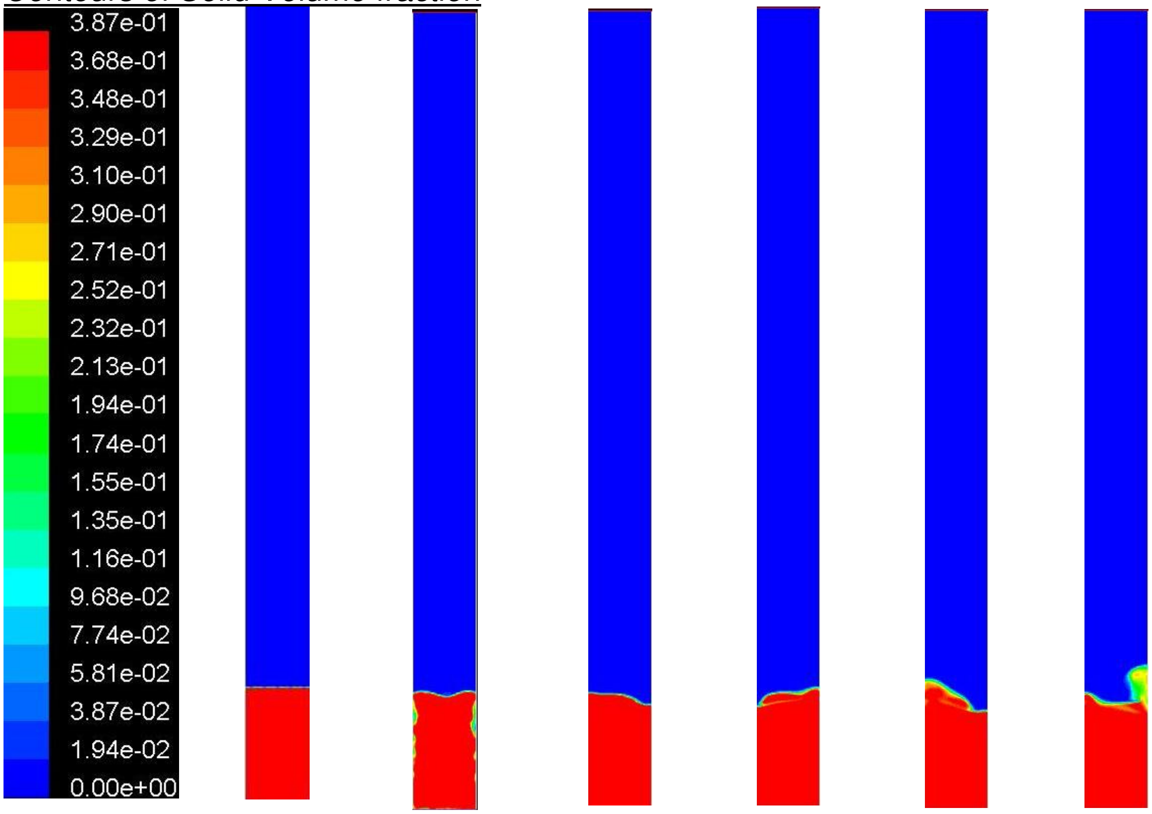


Figure-6.17 t=0s 0.3s 1.8s 2.5s 3.1s 3.5s

Contours of Liquid Volume fraction

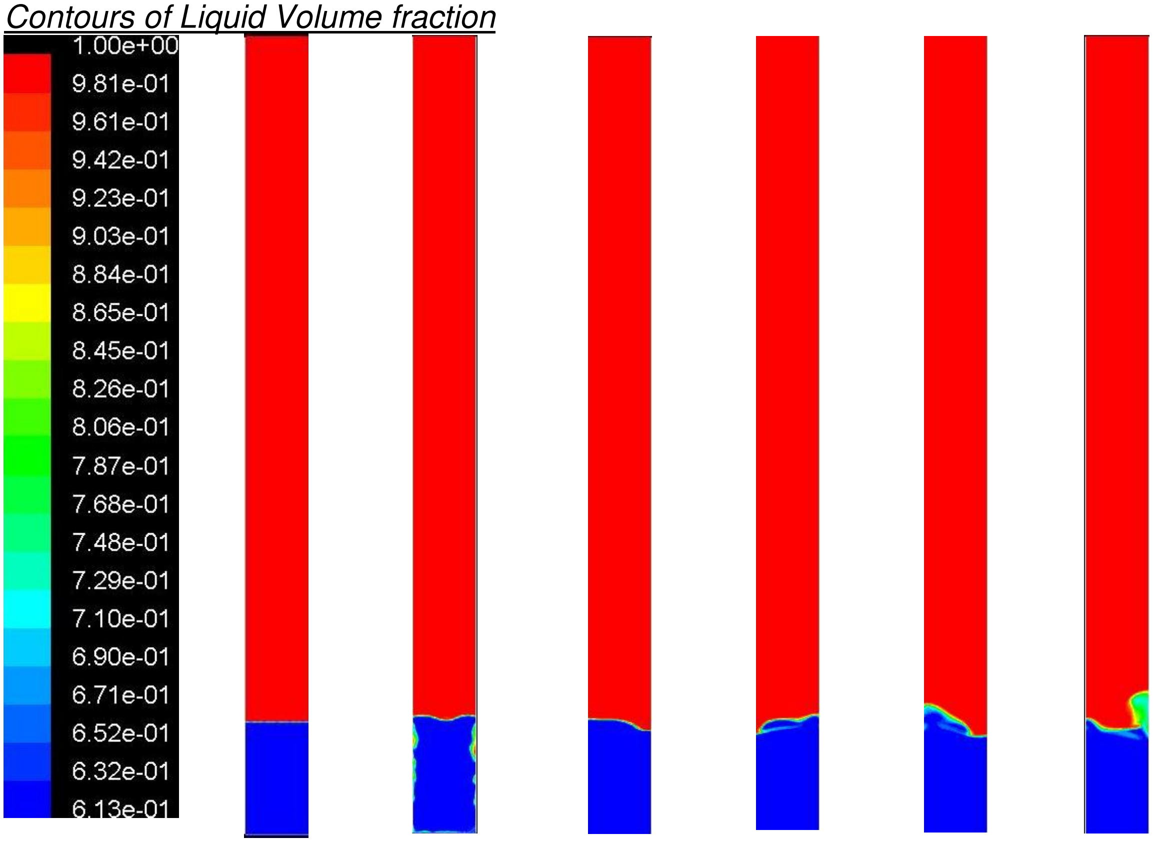


Figure-6.18 t=0s 0.3s 1.8s 2.5s 3.1s 3.5s

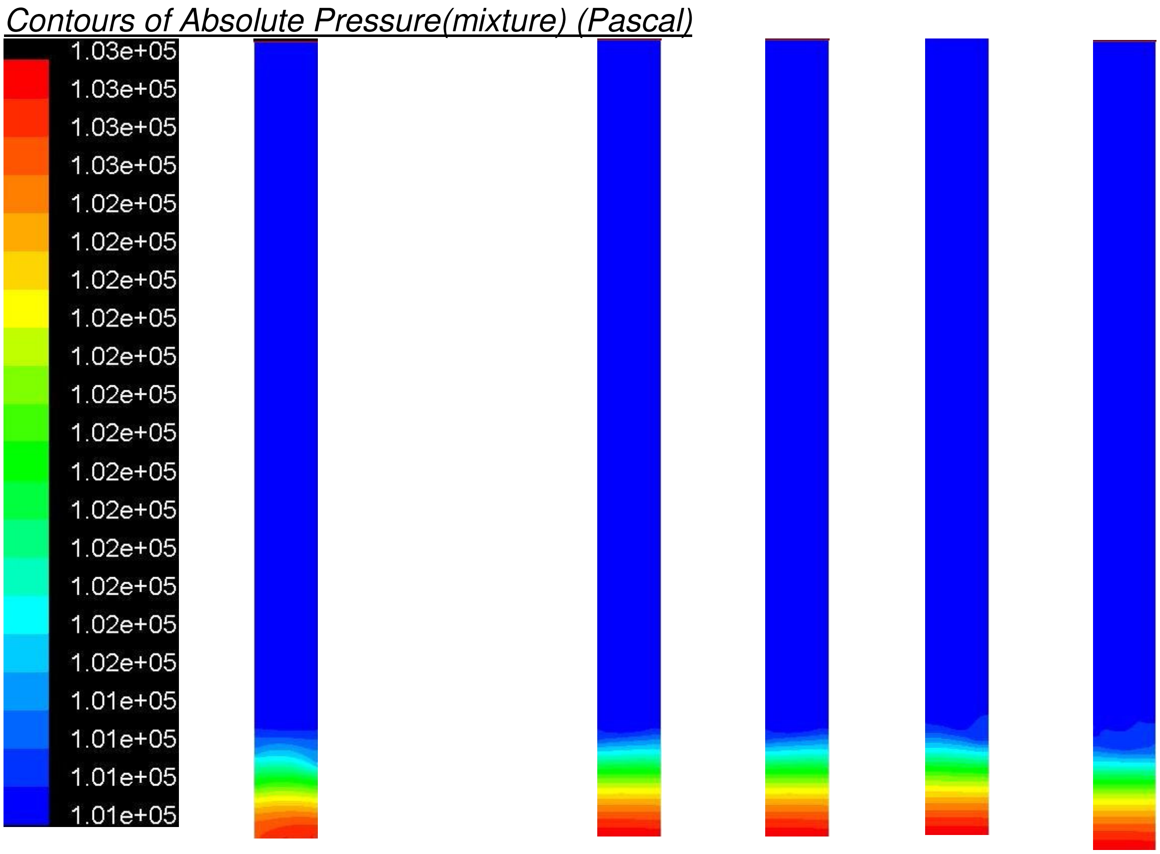


Figure-6.19 t=0s 1.8s 2.5s 3.1s 3.5s

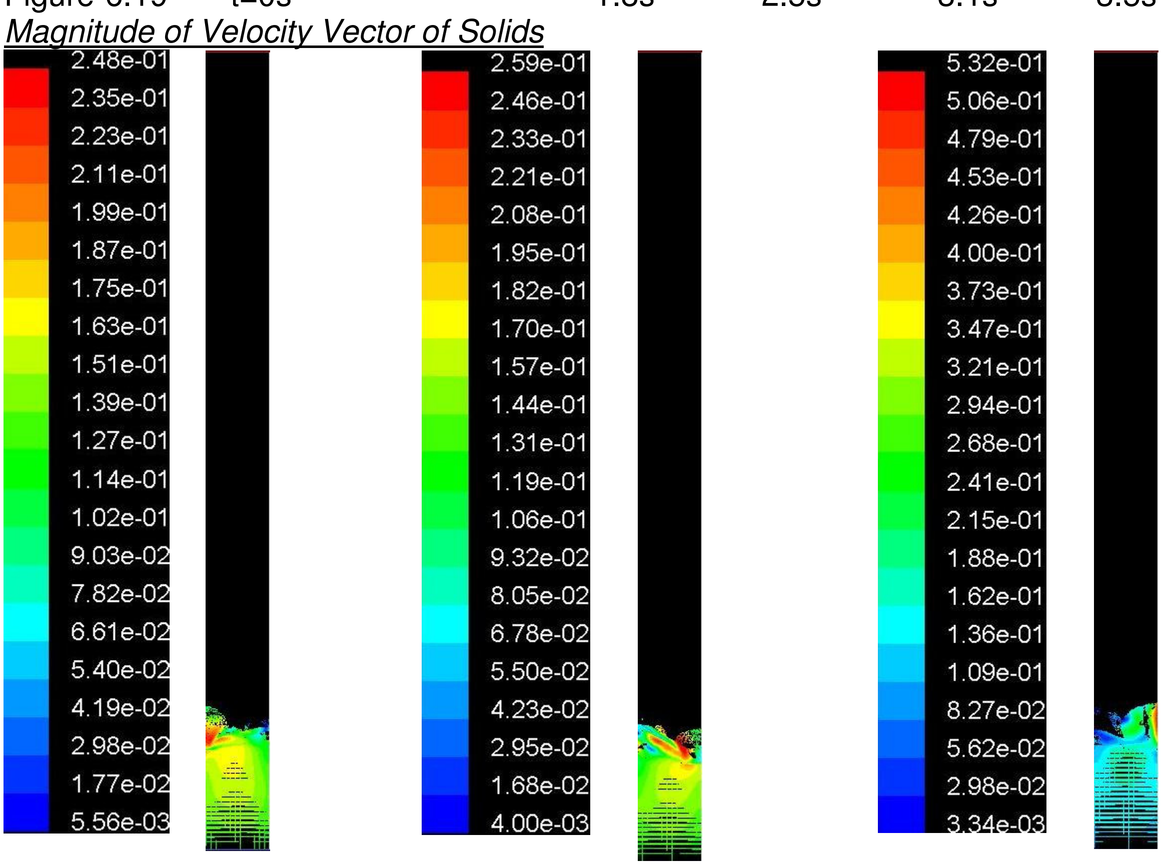


Figure-6.20 t=2.5s t=3.1s t=3.5s

Two-phase Iron-ore 0.149m/s liquid-velocity-

Contours of Solid Volume fraction

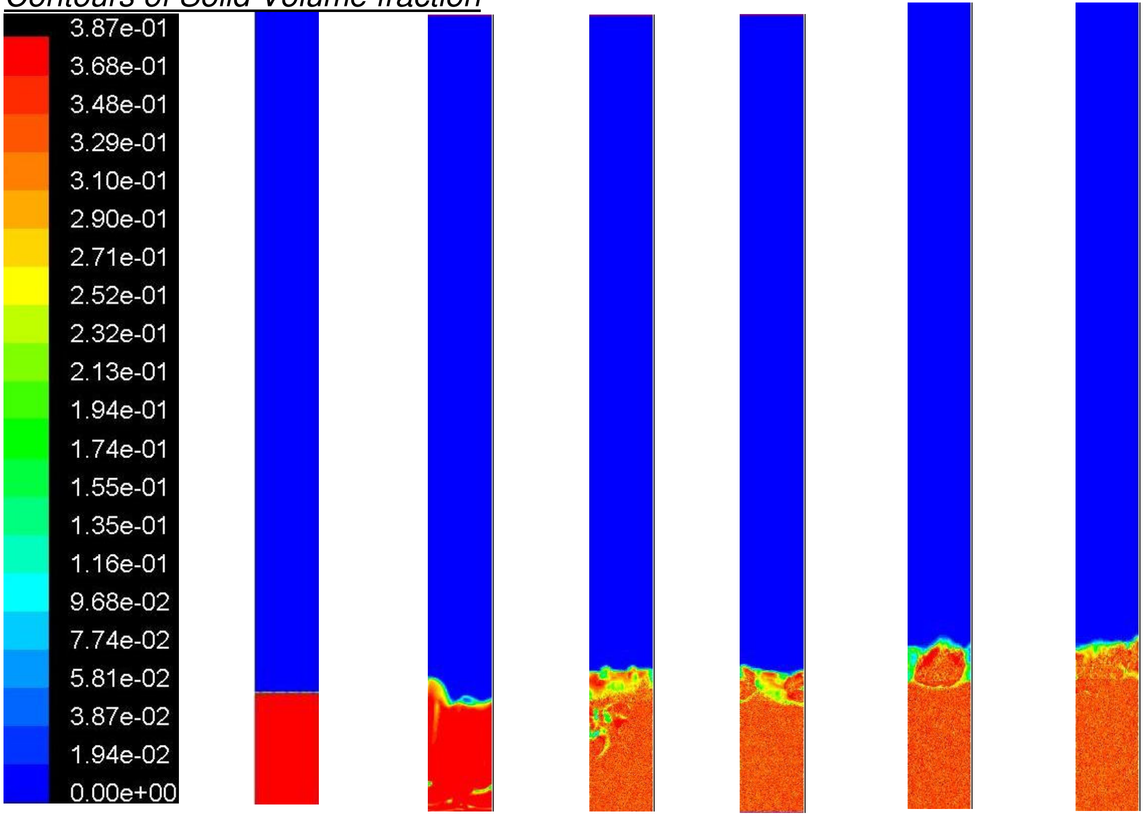


Figure-6.21 t=0s 0.5s 2s 5s 10s 20s

Contours of Liquid Volume fraction

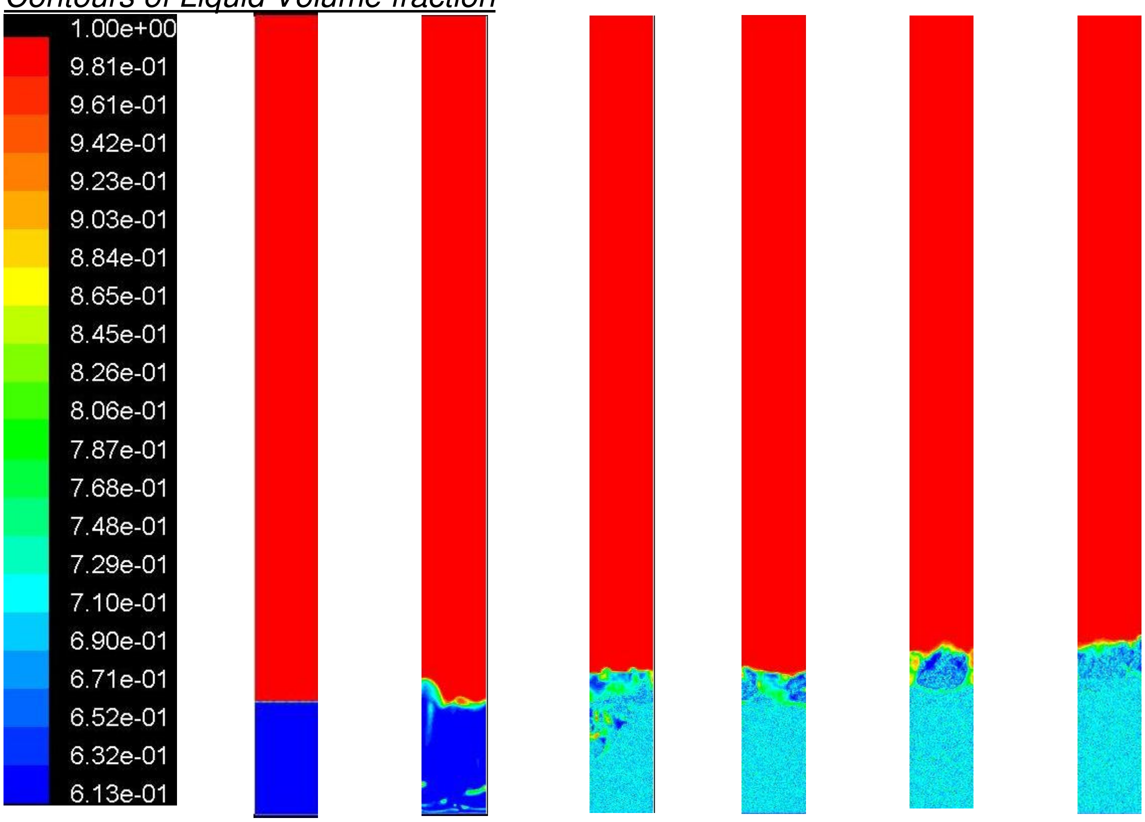


Figure-6.22 t= 0s 0.5s 2s 5s 10s 20s

Contours of Absolute Pressure(mixture) (Pascal)

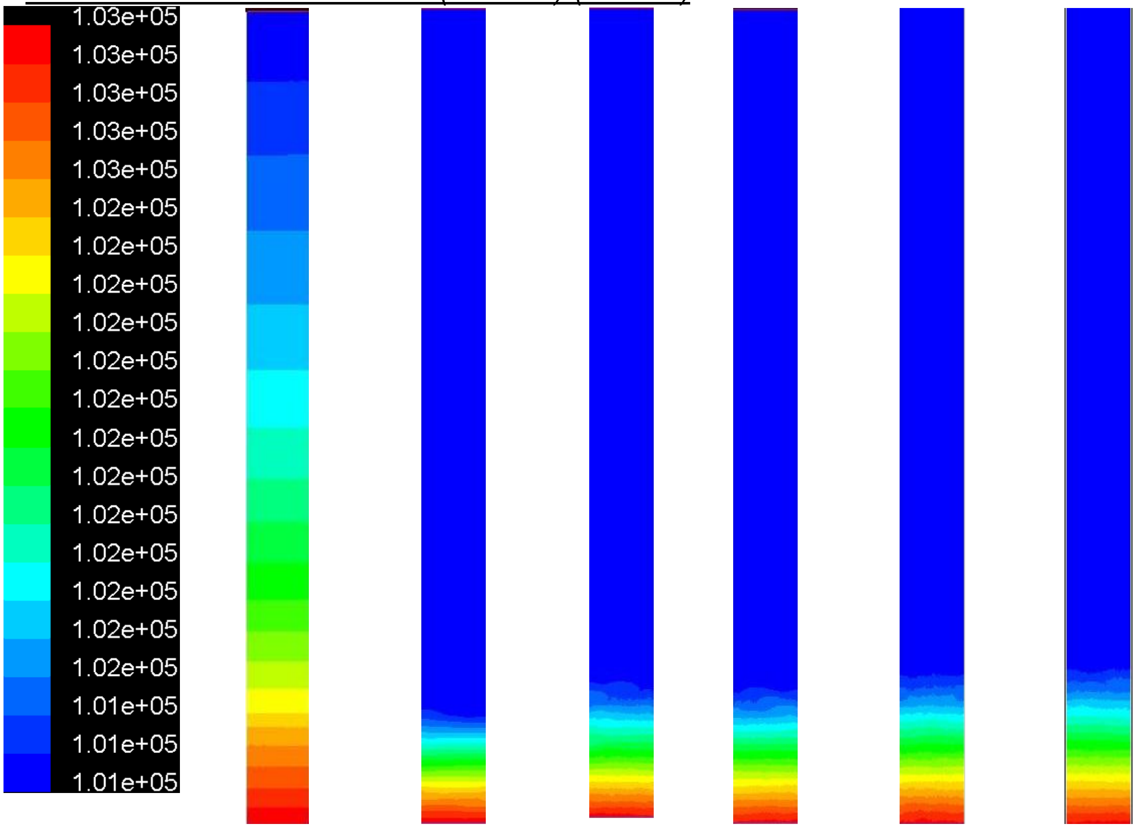


Figure-6.23 t=0s 0.5s 2s 5s 10s 20s

Magnitude of Velocity Vector of Solids

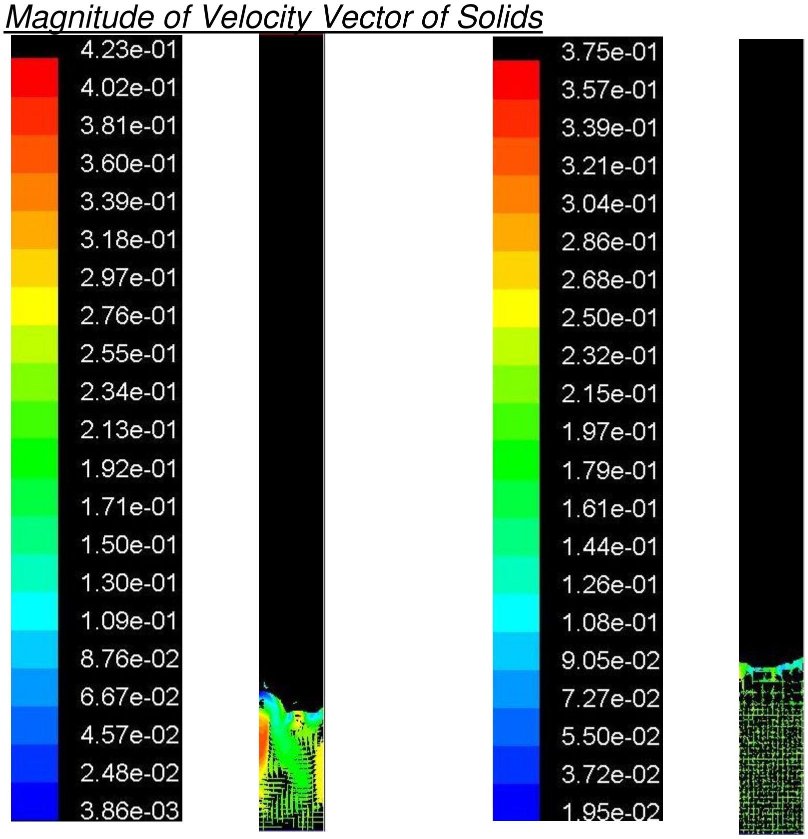


Figure-6.24 t=0.5s t=20s

Two-phase Coal 0.011m/s liquid-velocity-

Contours of Solid Volume fraction

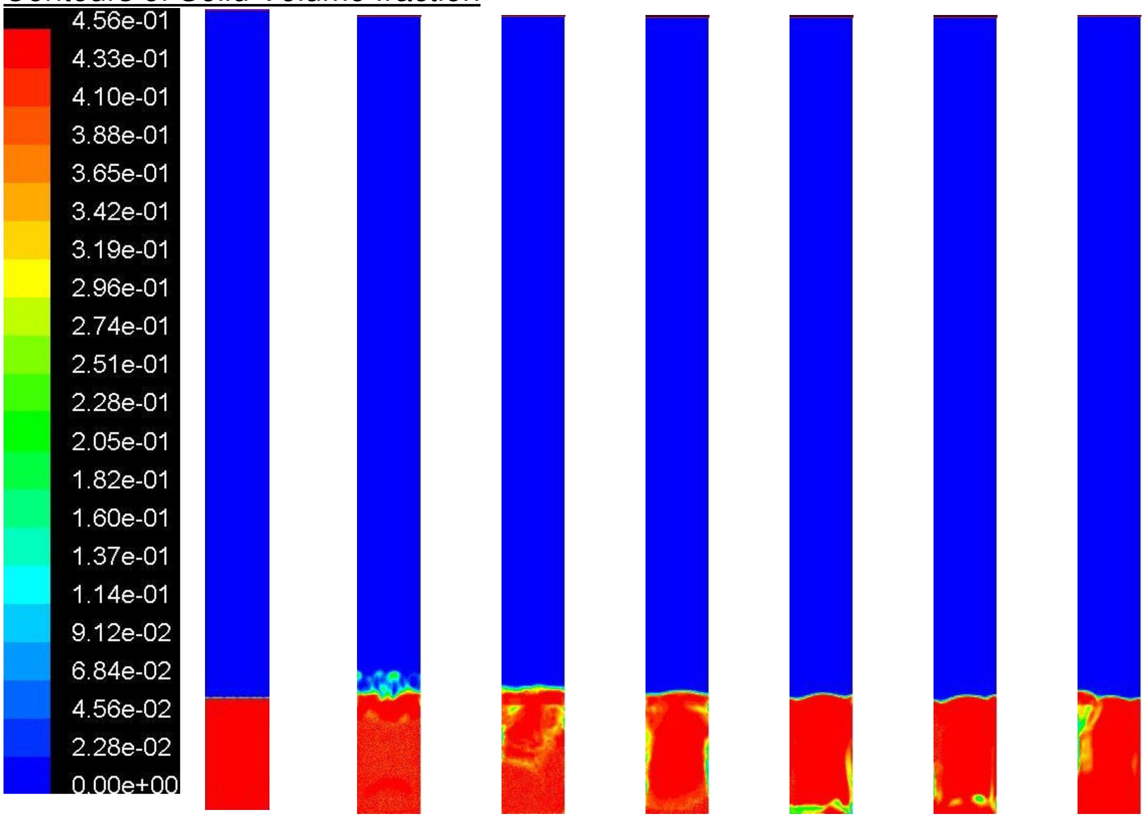


Figure-6.25 t= 0sec 0.2sec 0.4sec 0.6sec 0.8sec 1sec 1.4sec

Contours of Liquid Volume fraction

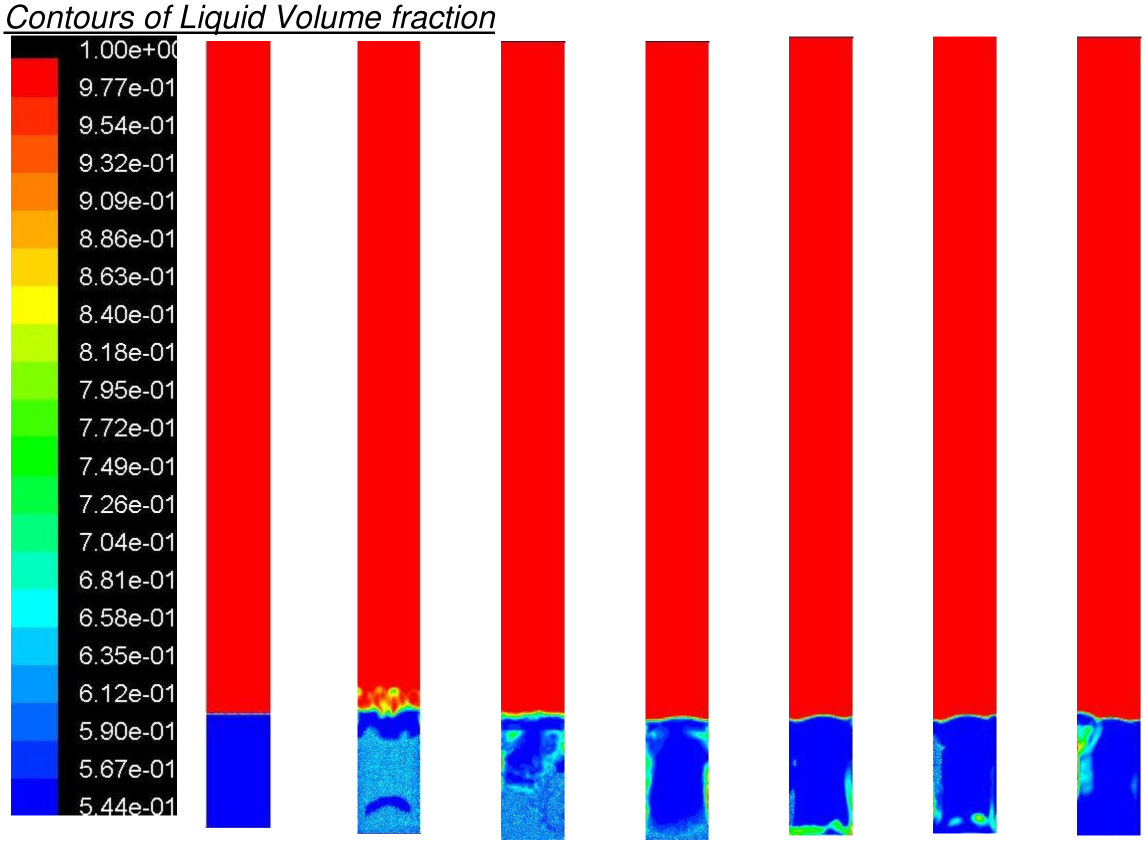


Figure-6.26 t=0sec 0.2sec 0.4sec 0.6sec 0.8sec 1sec 1.4sec

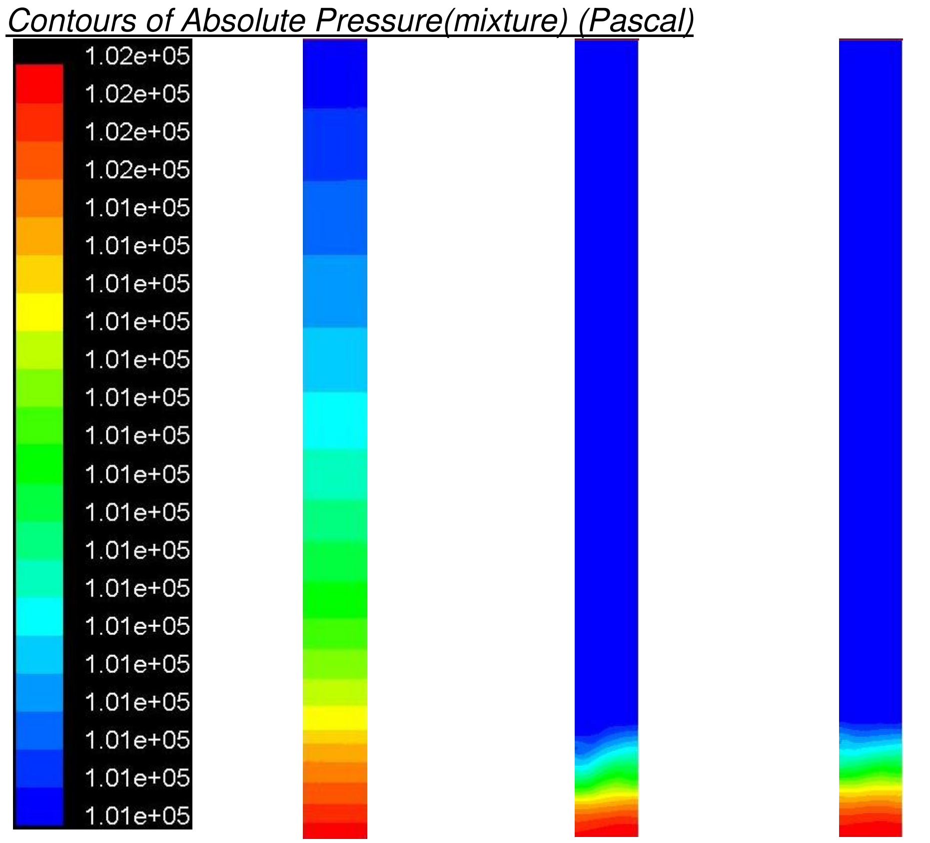


Figure-6.27 t=0sec t=1.2sec t=1.4sec

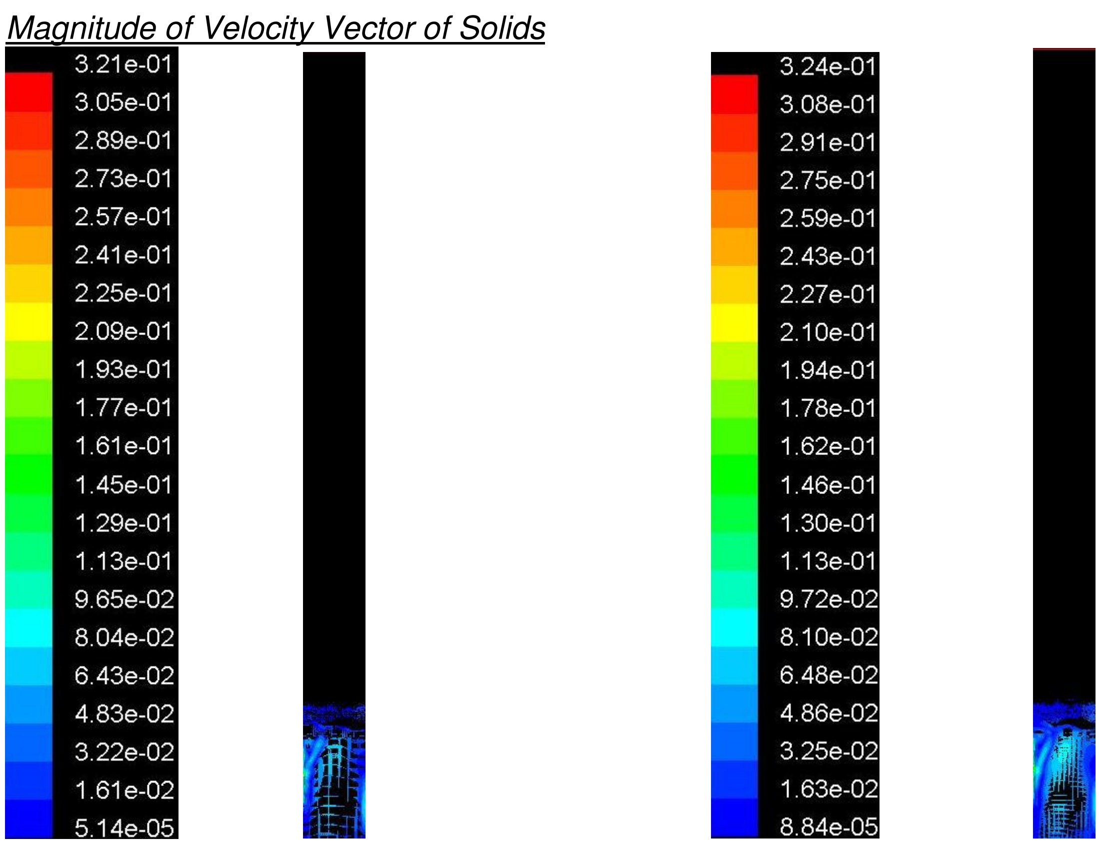


Figure-6.28 t=1.2sec t=1.4sec

Two-phase Coal 0.0255m/s liquid-velocity-

Contours of Solid Volume fraction

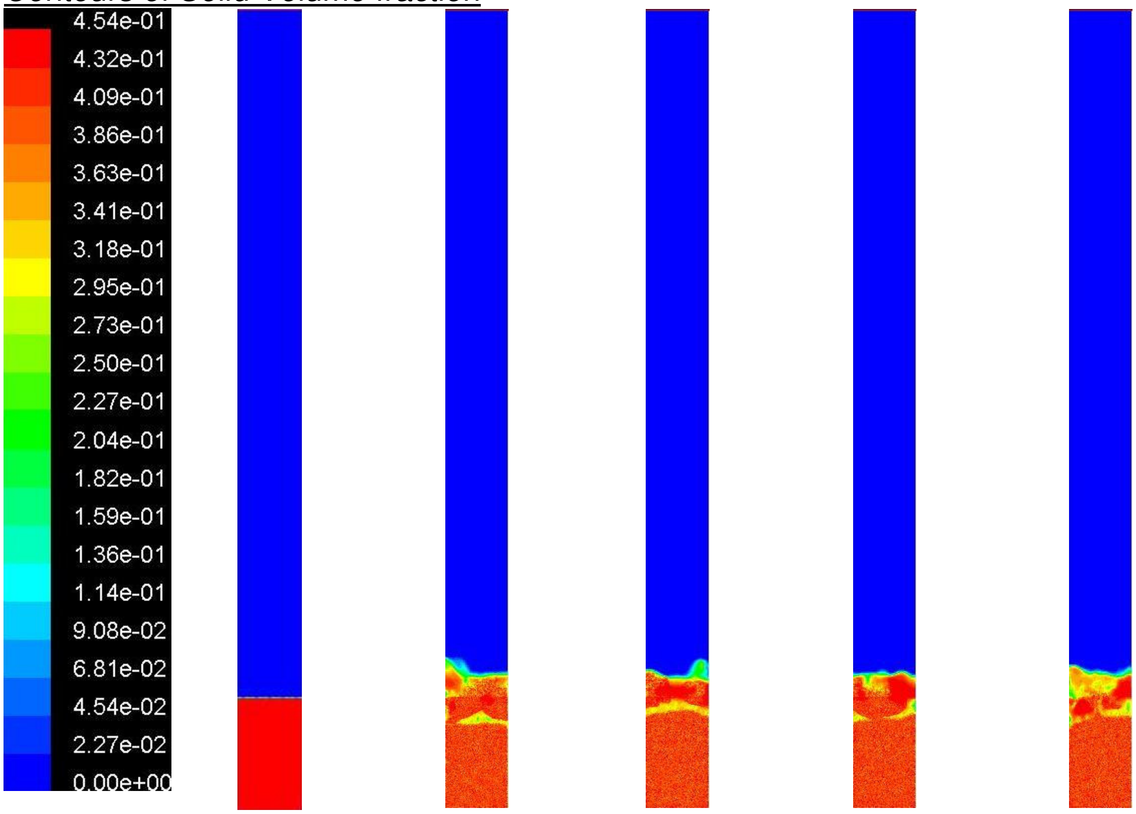


Figure-6.29 t= 0sec 1.5sec 4.5sec 7.5sec 10.5sec

Contours of Liquid Volume fraction

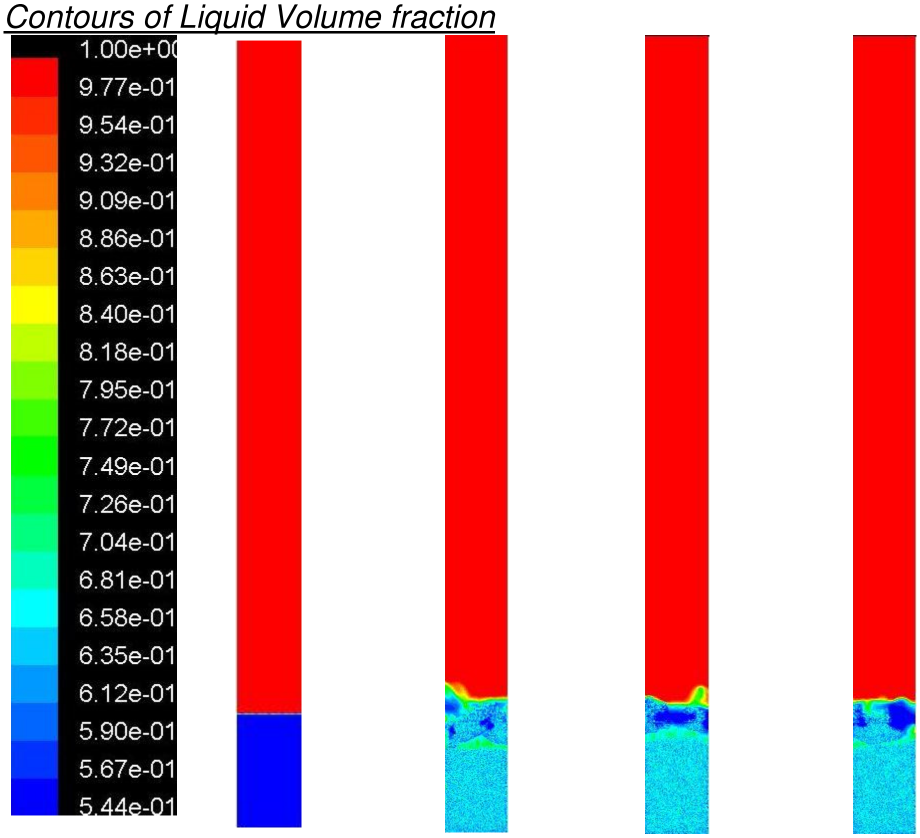


Figure-6.30 t=0sec 1.5sec 4.5sec 7.5sec

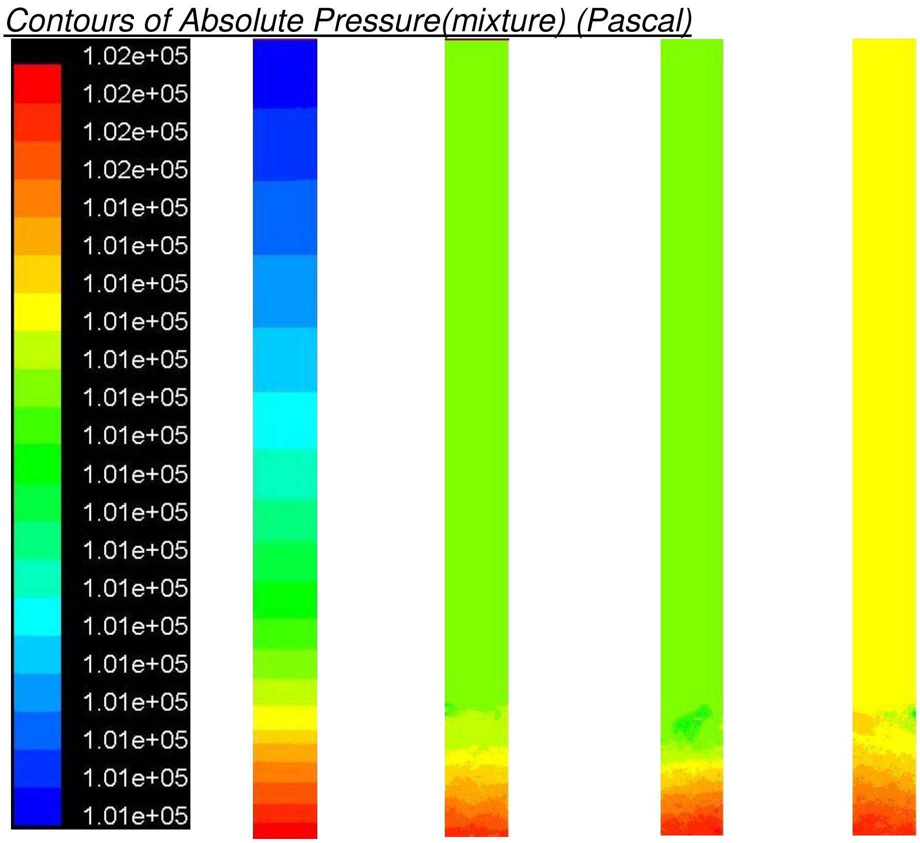


Figure-6.31 t=0sec 3sec 6sec 9sec

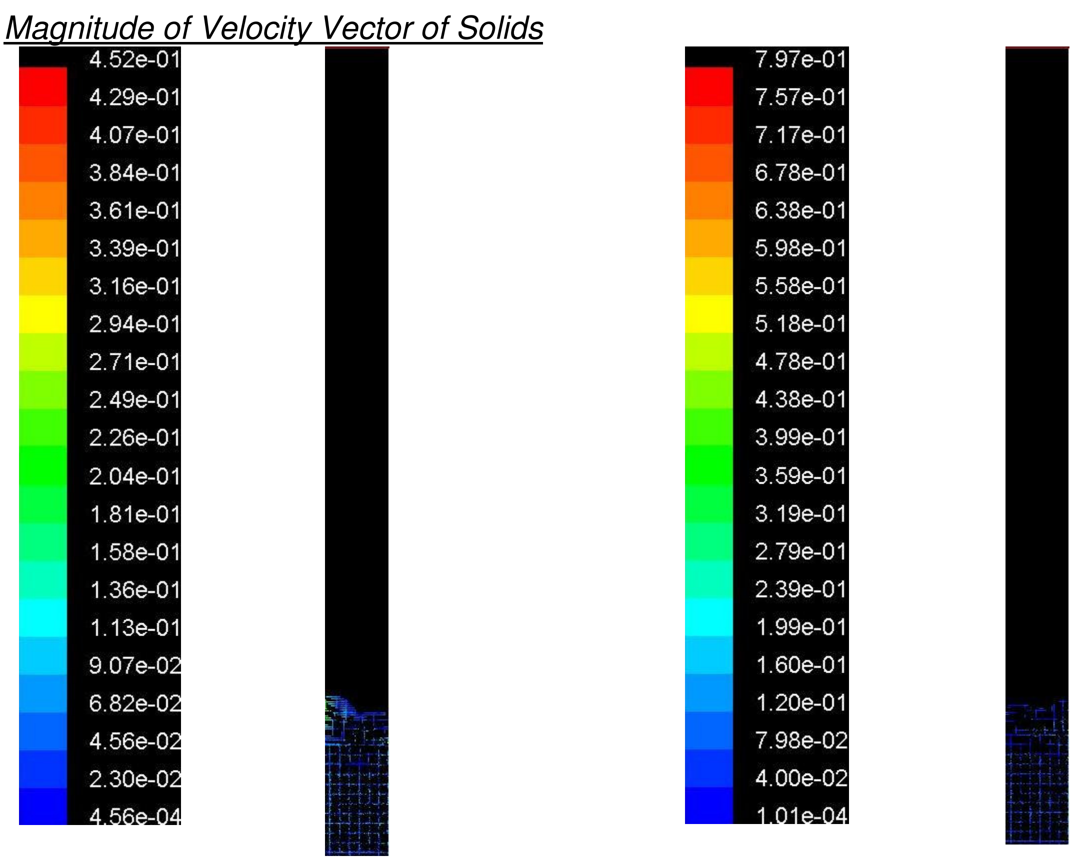


Figure-6.32 t=1.5sec t=10.5sec

Two-phase Coal 0.0637m/s liquid-velocity-

Contours of Solid Volume fraction

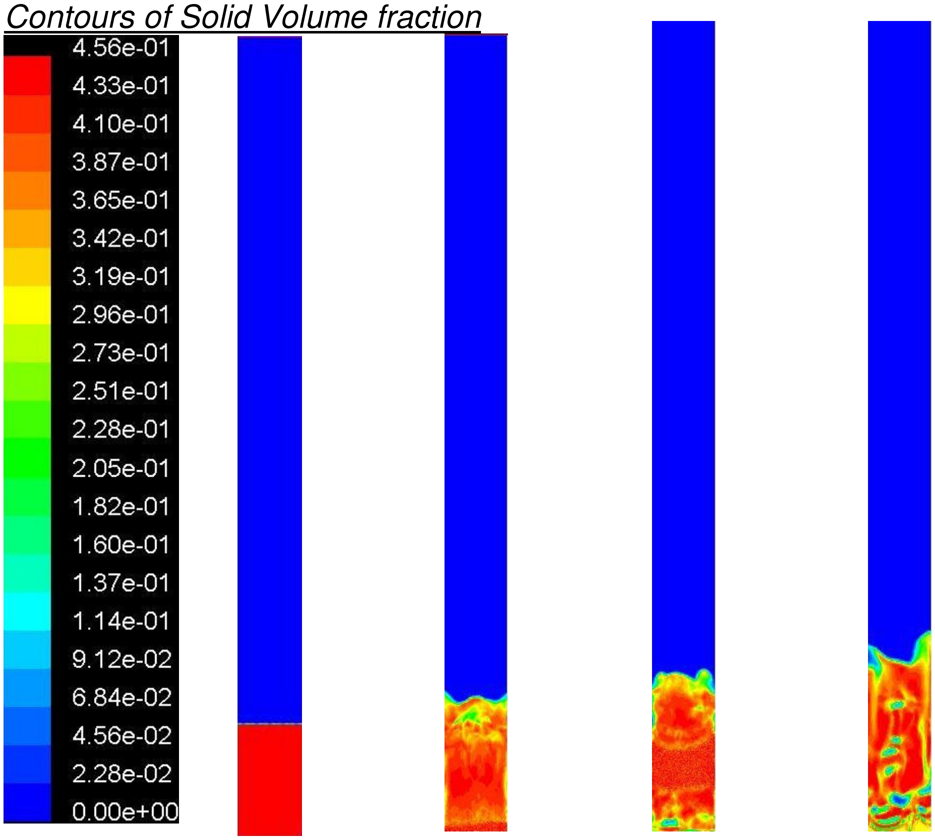


Figure-6.33 t=0sec 1.2sec 1.8sec 3.6sec

Contours of Liquid Volume fraction

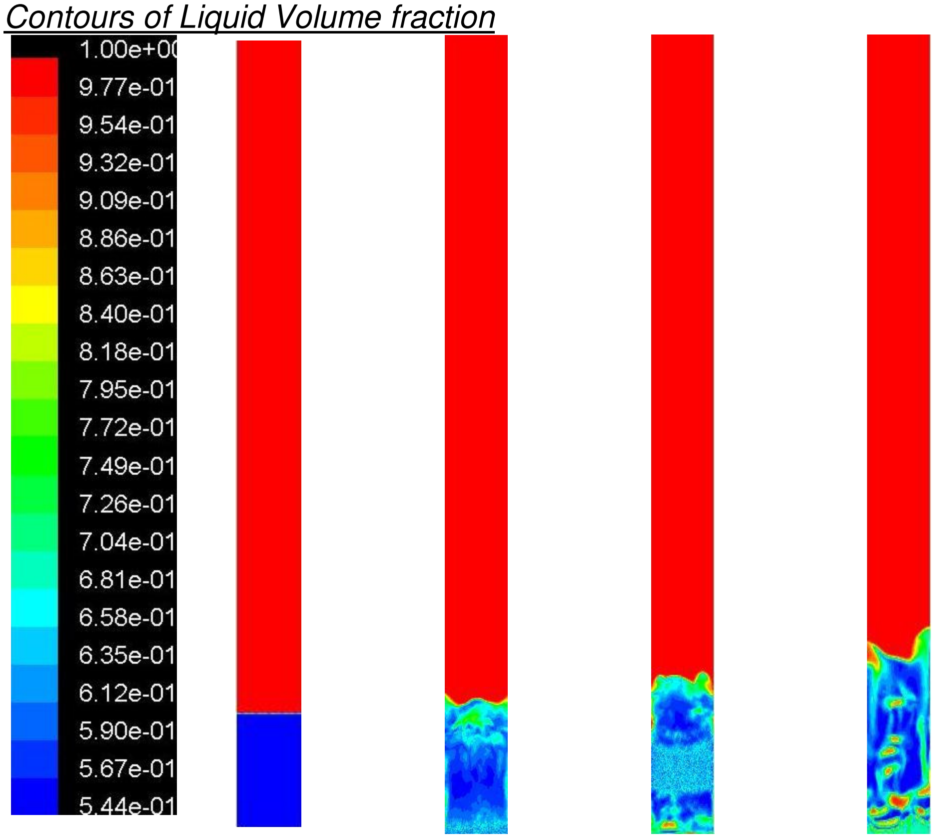


Fig-6.34 t= 0sec 1.2sec 1.8sec 3.6sec

Contours of Absolute Pressure(mixture) (Pascal)

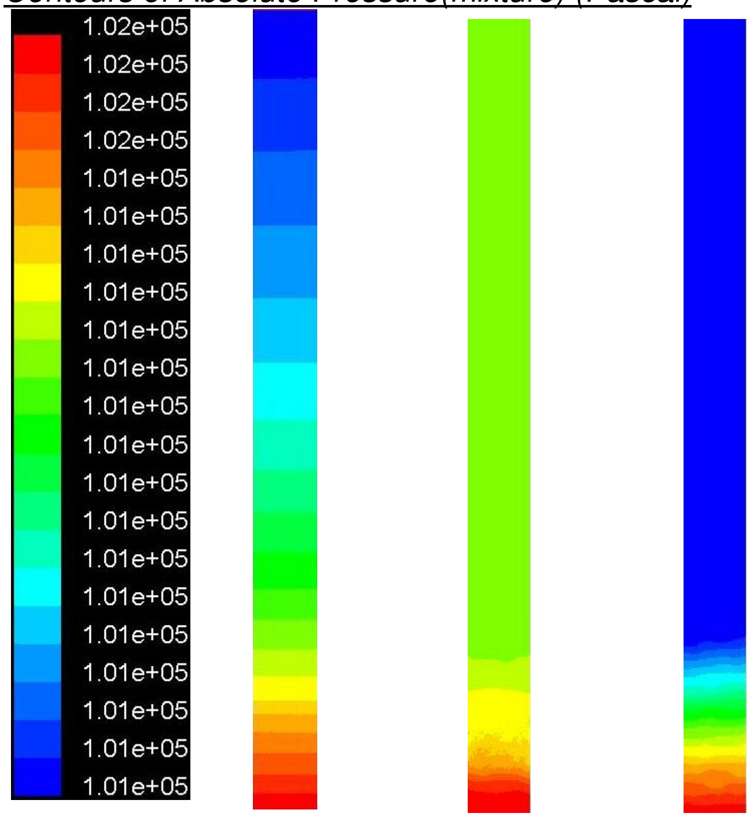


Fig-6.35 t= 0sec 1.8sec 3.6sec

Magnitude of Velocity Vector of Solids

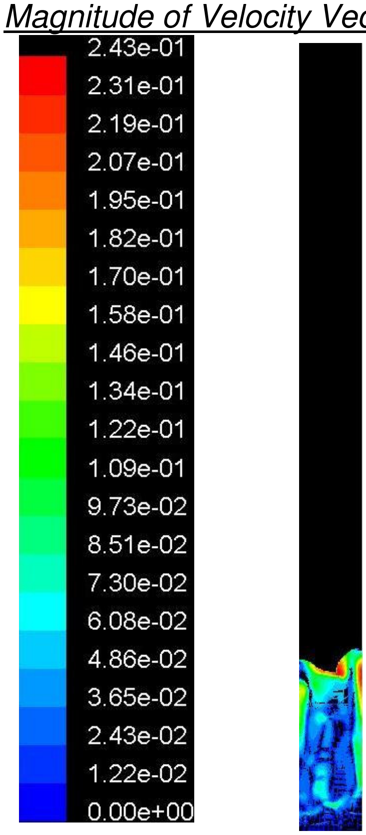


Fig-6.36 t=3.6sec

Two-phase Dolomite 0.021m/s liquid-velocity-

Contours of Solid Volume fraction

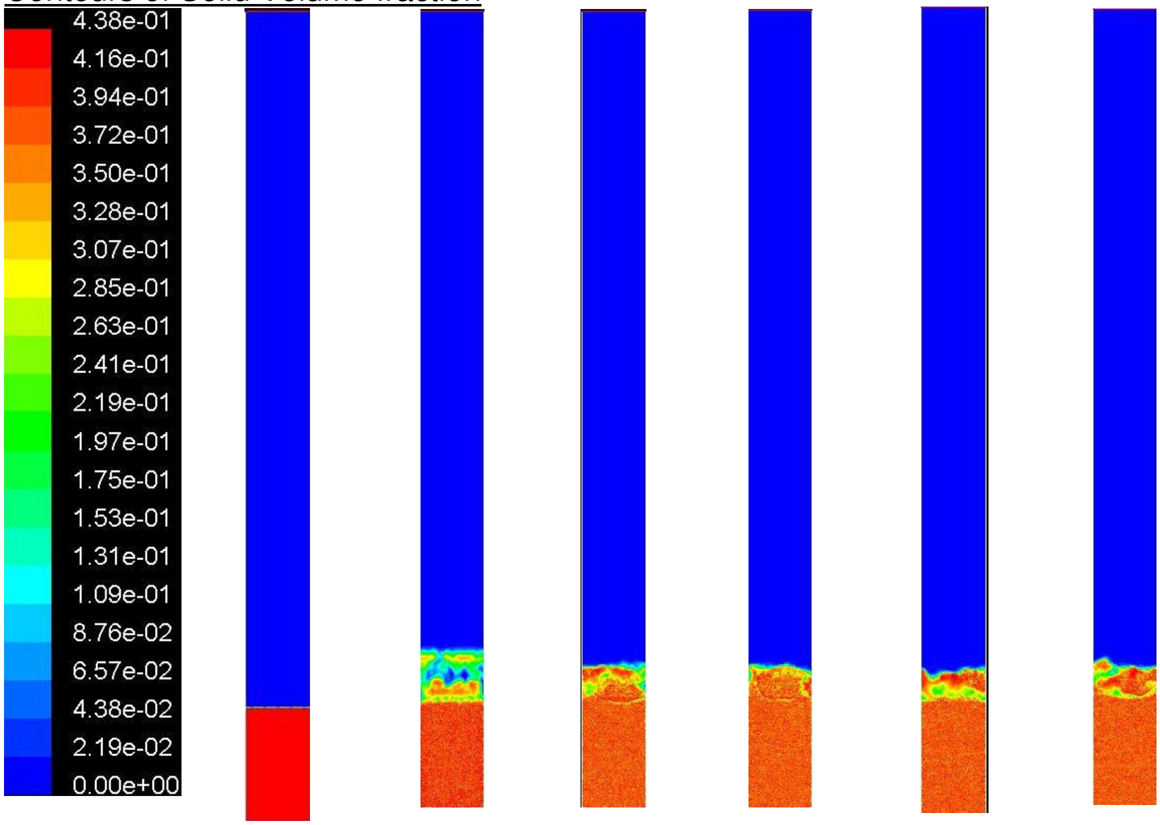


Fig-6.37 t=0sec 1 sec 3 sec 5sec 7sec 9sec

Contours of Liquid Volume fraction

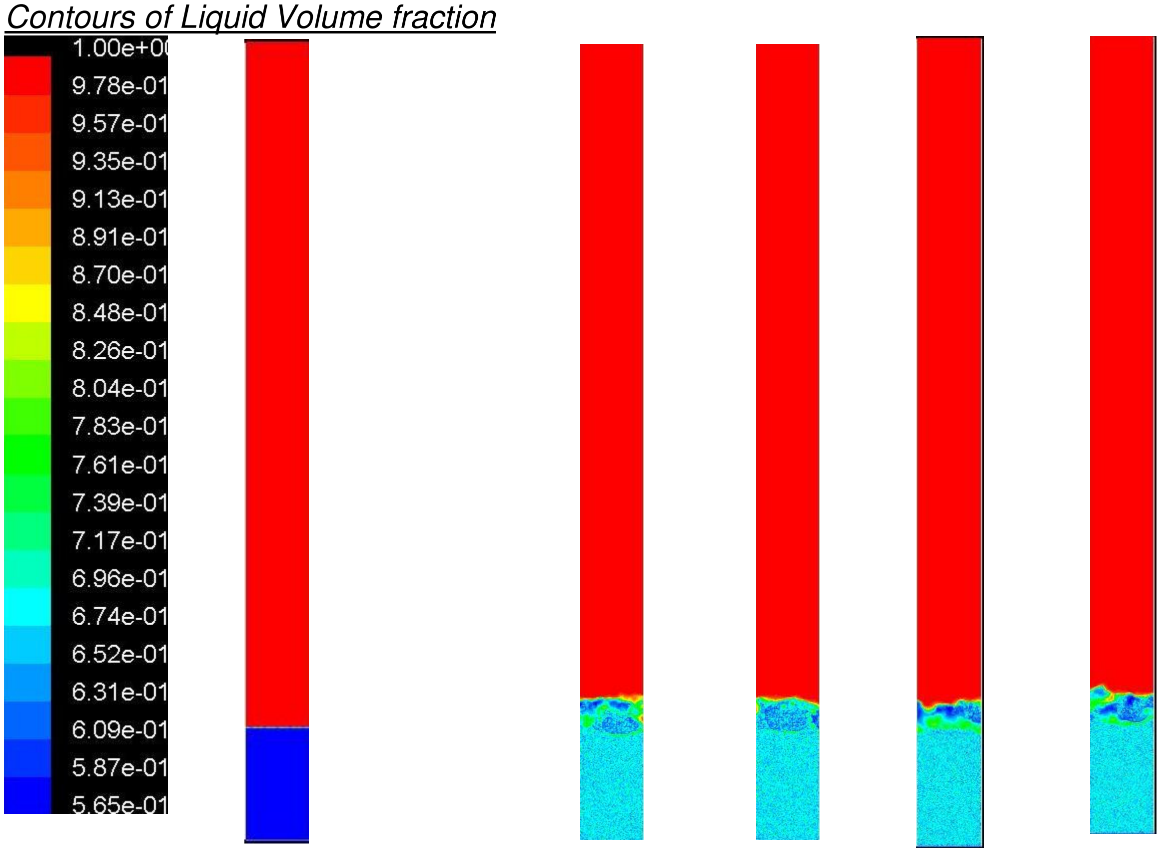


Fig-6.38 t = 0 sec 3 sec 5sec 7sec 9sec

Contours of Absolute Pressure(mixture) (pascal)

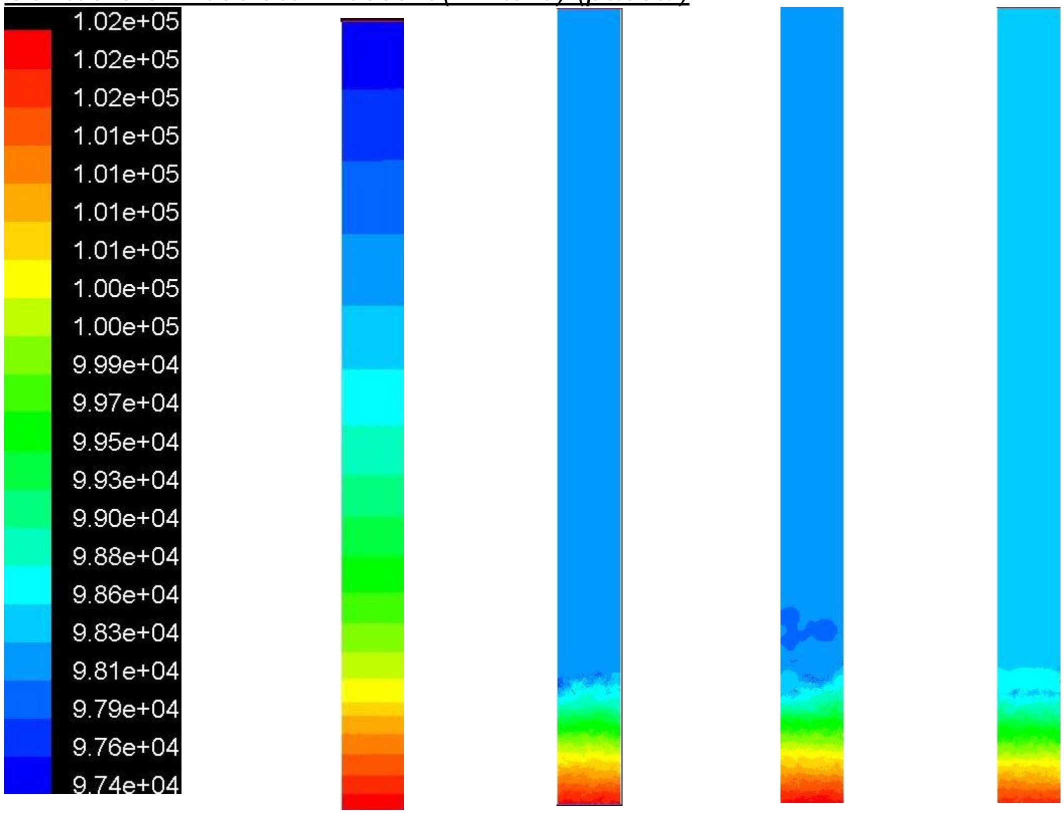


Fig-6.39 t = 0sec t =5sec t = 7sec t=9sec

Magnitude of Velocity Vector of Solids

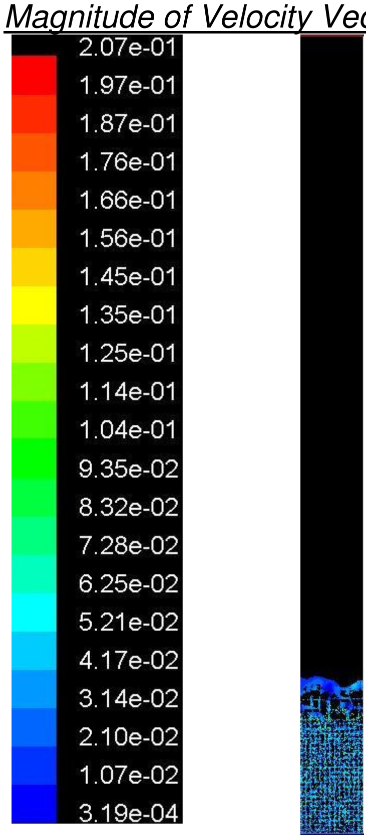


Fig-6.40 t = 9sec

Two-phase Dolomite 0.0531m/s liquid-velocity-

Contours of Solid Volume fraction

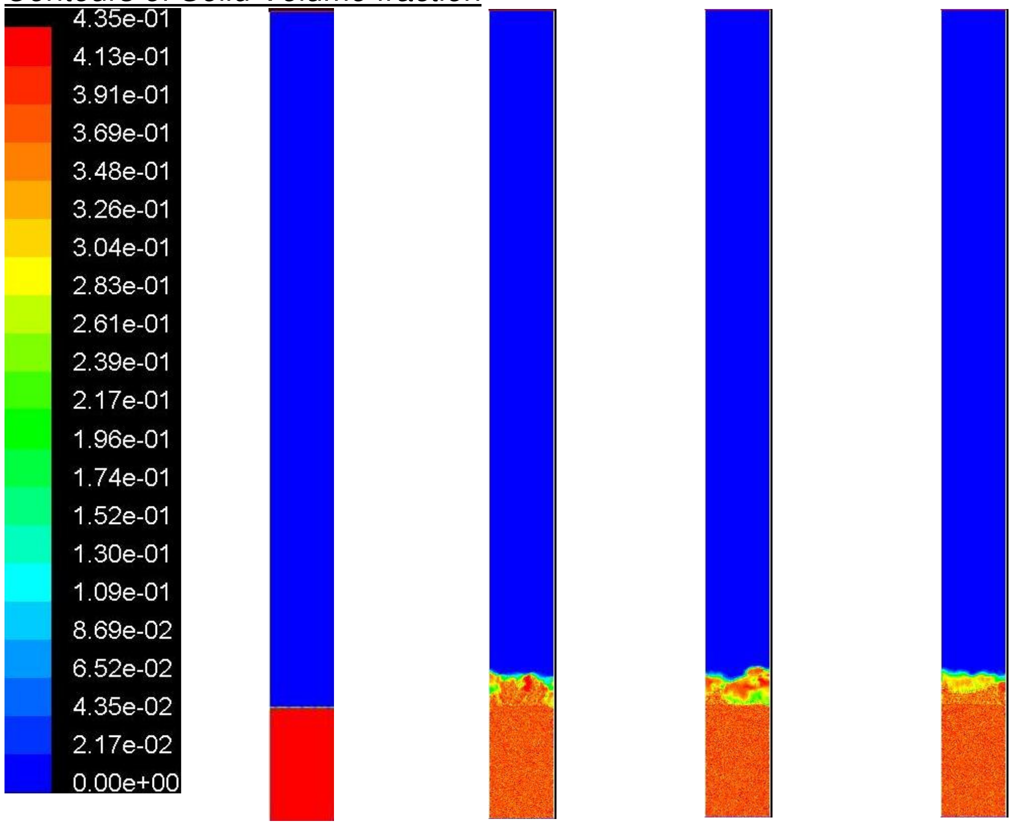


Fig-6.41 t = 0 sec t = 1.2 sec t = 2.4 sec t=3.2sec

Contours of Liquid Volume fraction

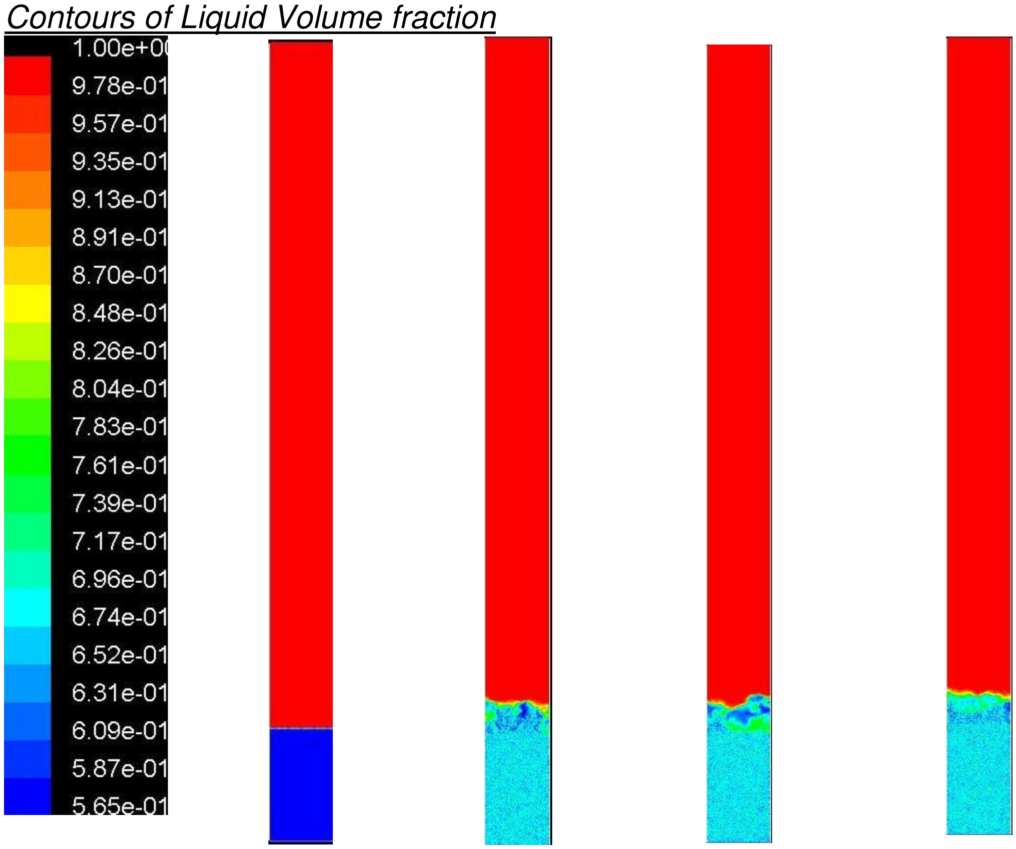


Fig-6.42 t = 0 sec t = 1.2 sec t = 2.4 sec t=3.2sec

Contours of Absolute Pressure(mixture) (pascal)

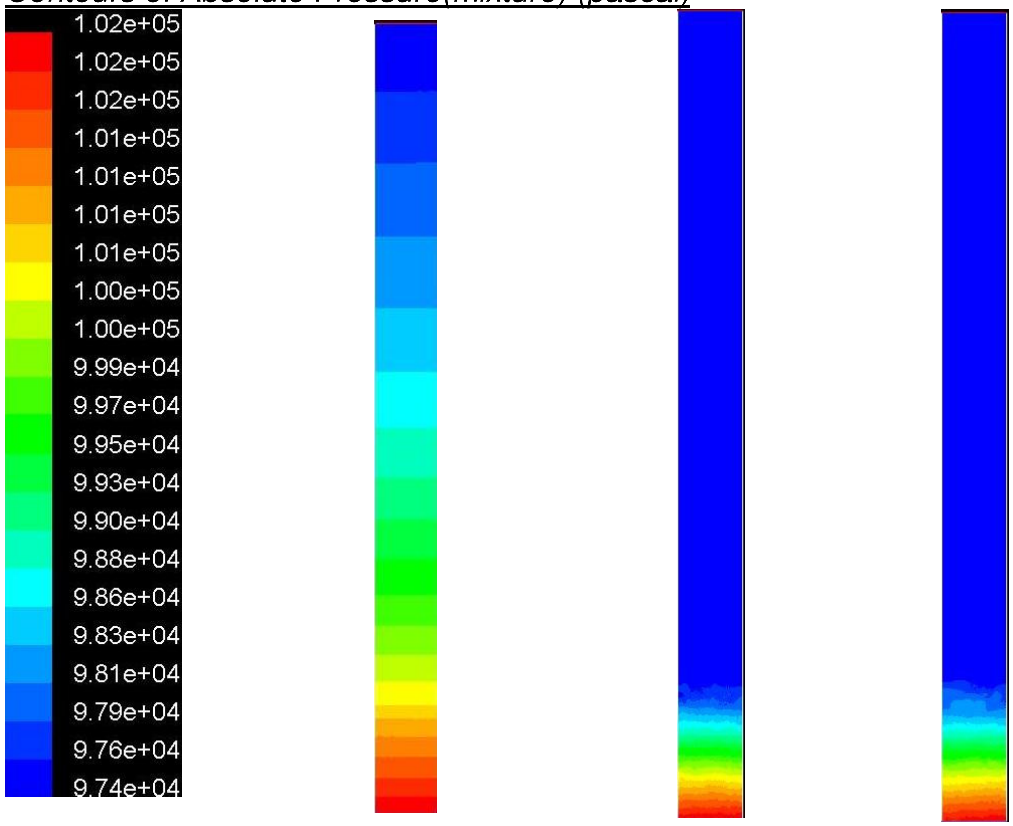


Fig-6.43 t = 0 sec t = 3.0 sec t = 3.2 sec

Magnitude of Velocity Vector of Solids

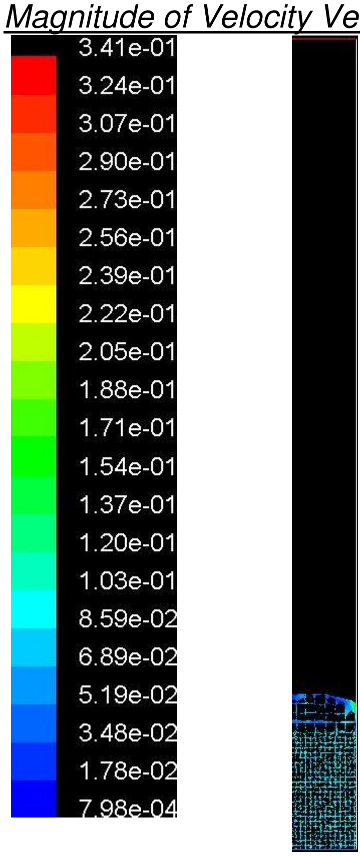


Fig-6.44 t = 3.2 sec

Two-phase Dolomite 0.12m/s liquid-velocity-

Contours of Solid Volume fraction

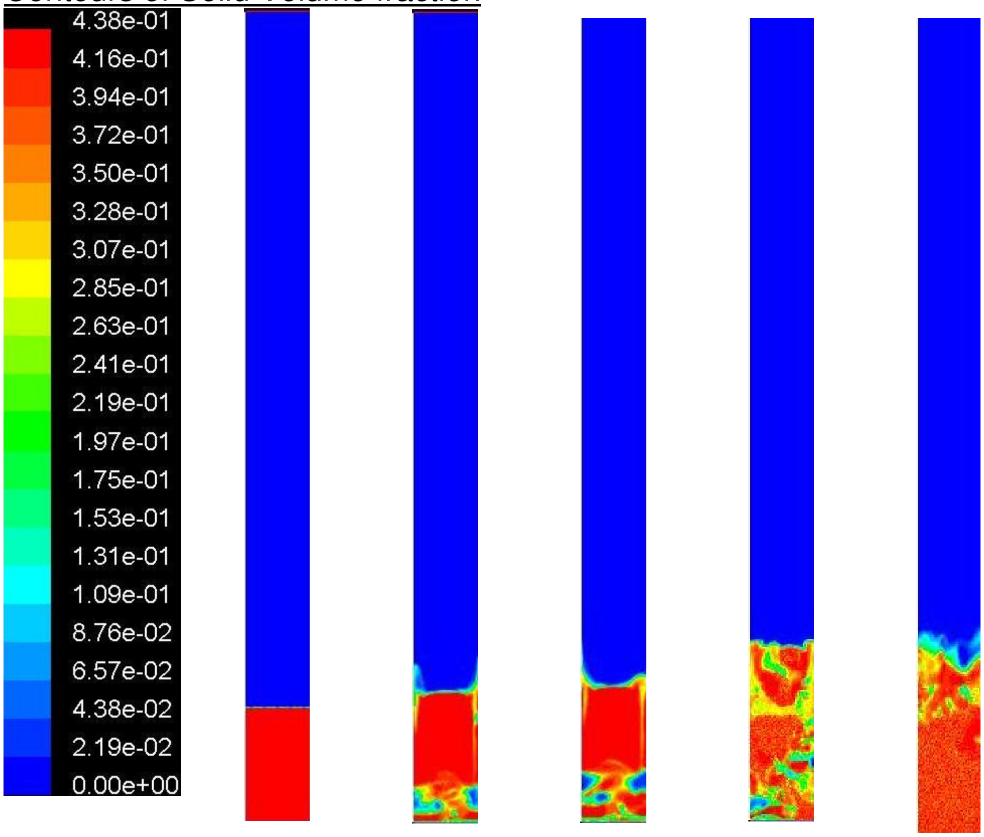


Fig-6.45 t=0sec 1.2sec 1.4sec 1.6sec 4sec

Contours of Liquid Volume fraction

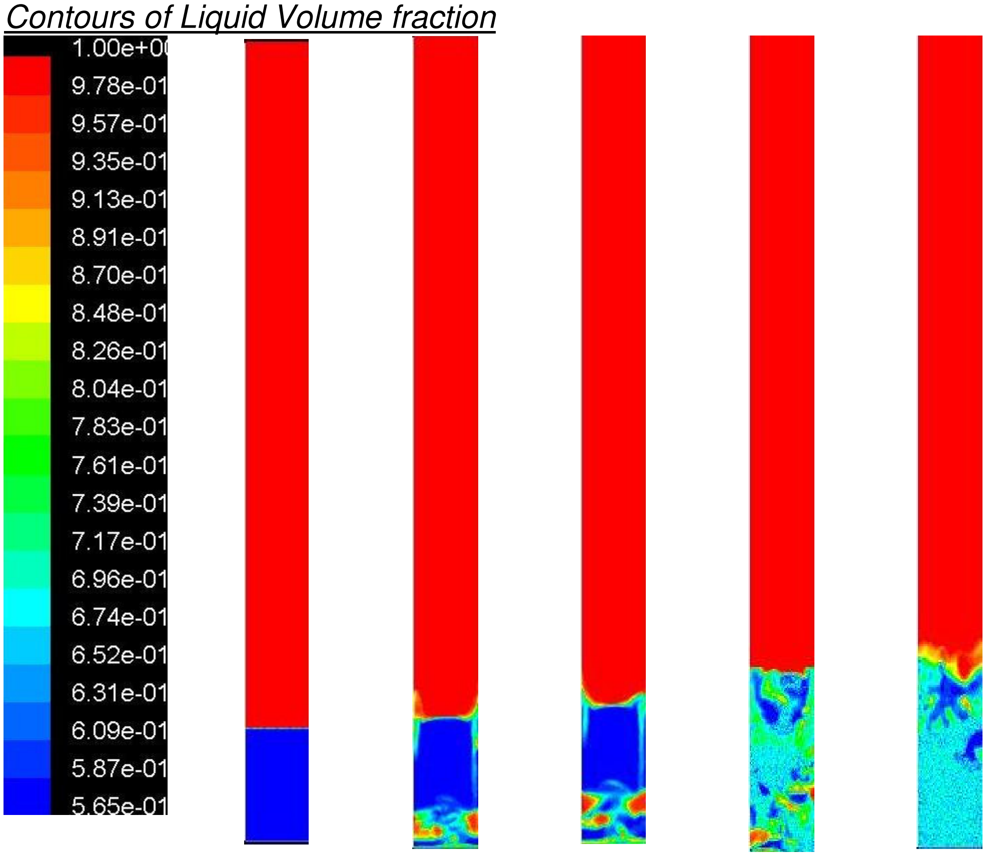


Fig-6.46 t =0 sec 1.2sec 1.6sec 1.8sec 4sec

Contours of Absolute Pressure(mixture) (pascal)

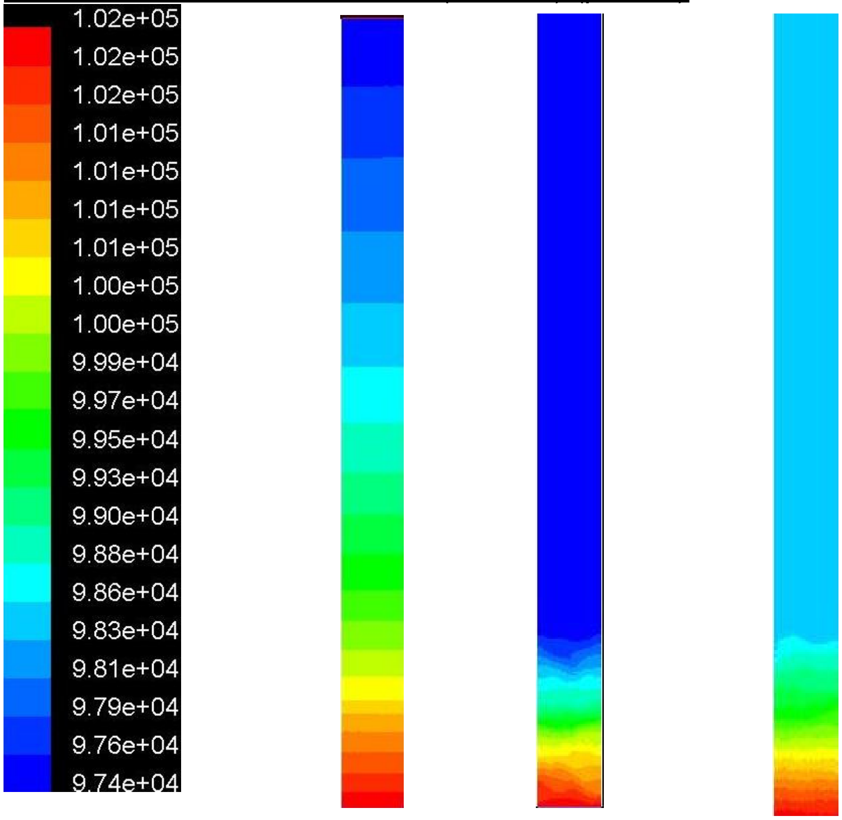


Fig-6.47 t = 0sec t =1.2sec t = 4sec

Magnitude of Velocity Vector of Solids

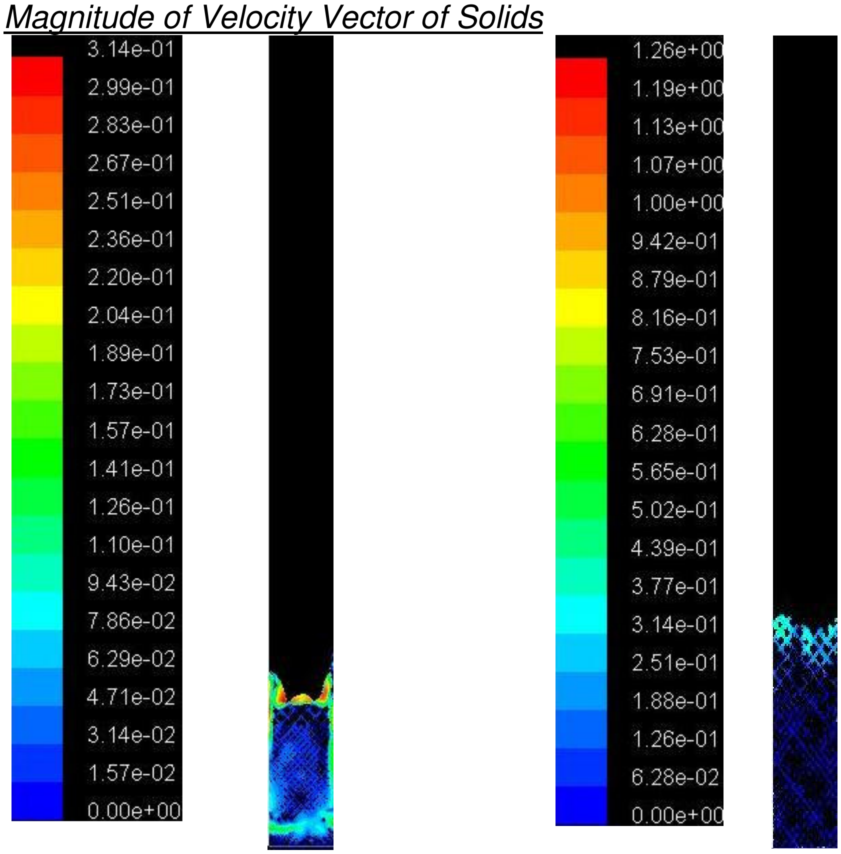


Fig-6.48 t = 1.2sec t=4sec

Three-phase Laterite 0.2m/s liquid-velocity & 0.05m/s gas-velocity-

Contours of Solid Volume fraction

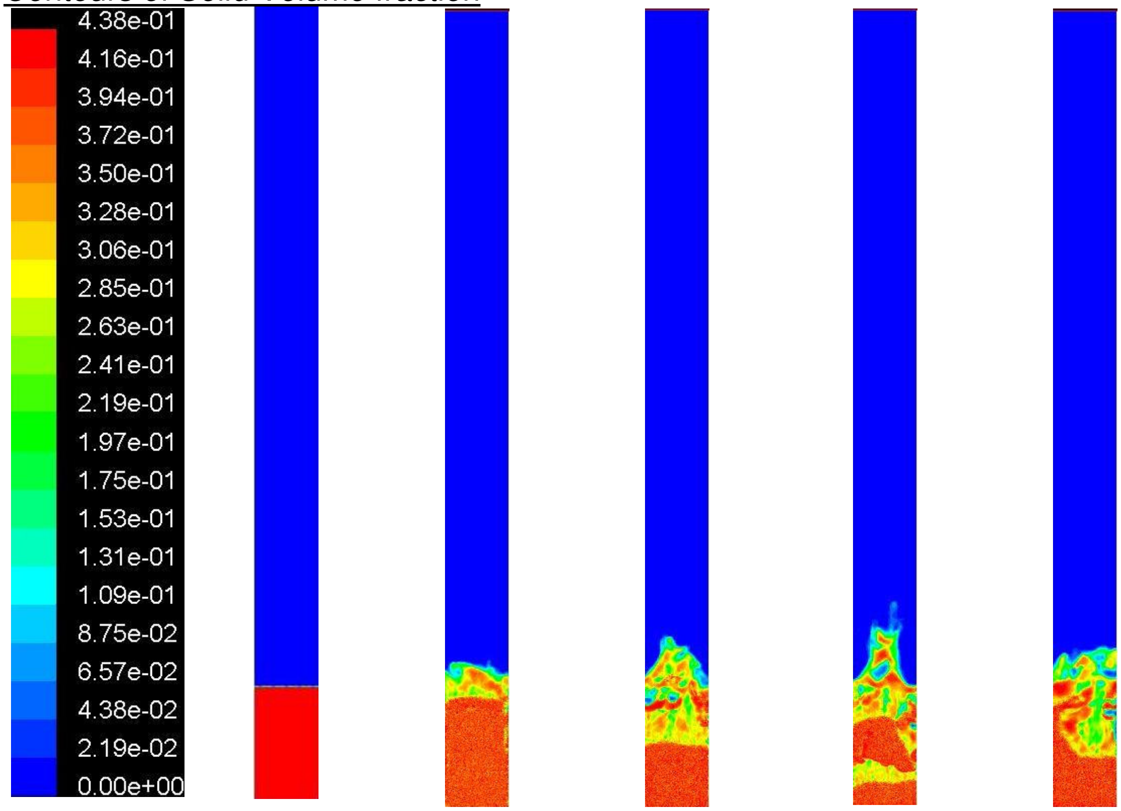


Fig-6.49 t= 0s 0.3s 0.9s 1.2s 1.5s

Contours of Liquid Volume fraction

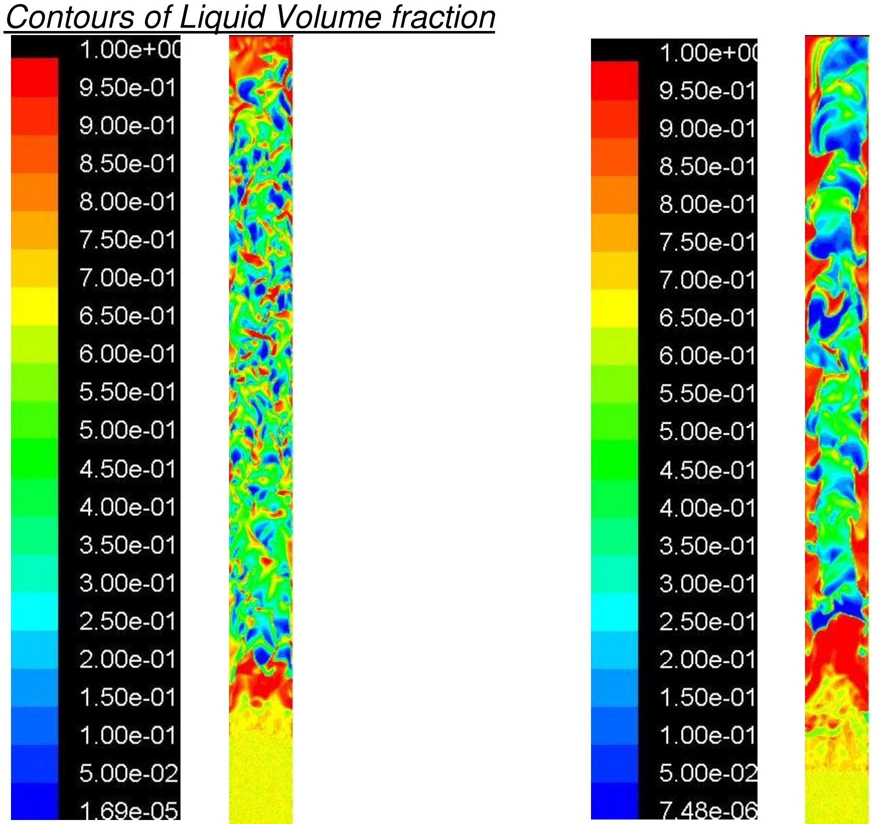


Fig-6.50 t=0.6s t= 1.5s

Contours of Gas Volume fraction

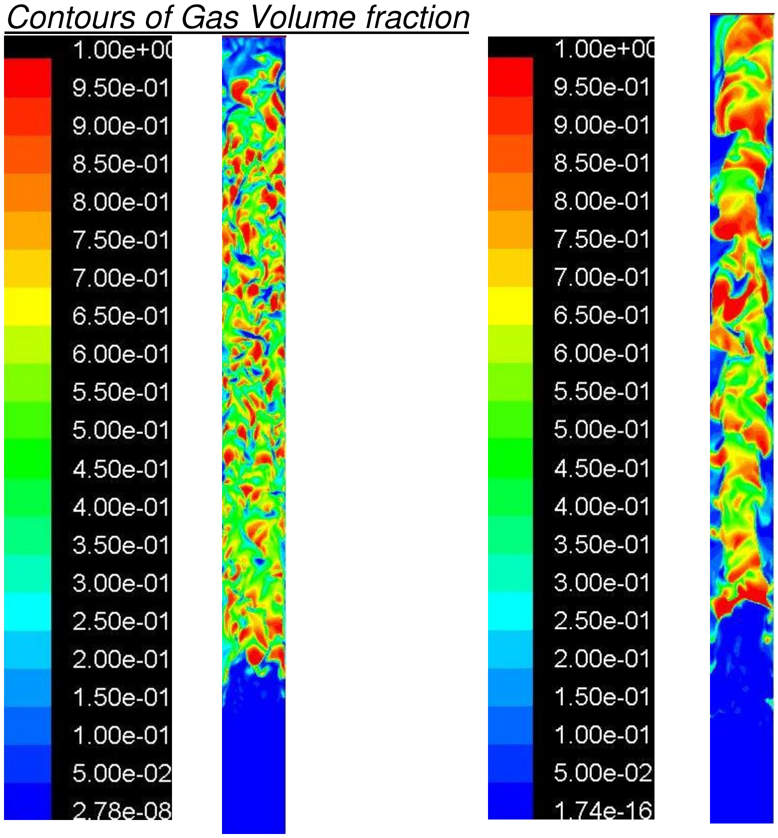


Fig-6.51 t=0.6s t= 1.5s

Contours of Absolute Pressure(mixture) (Pascal)

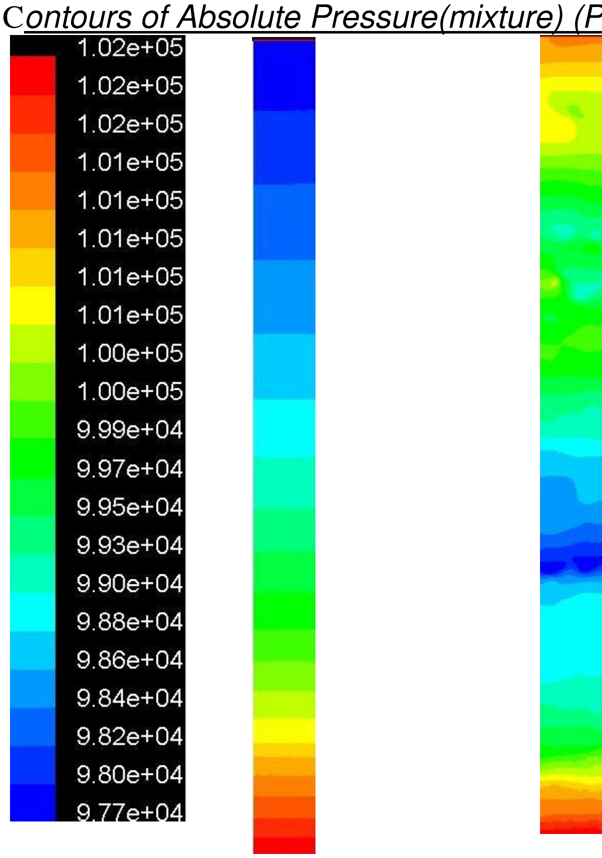


Fig-6.52 t=0s 1.5s

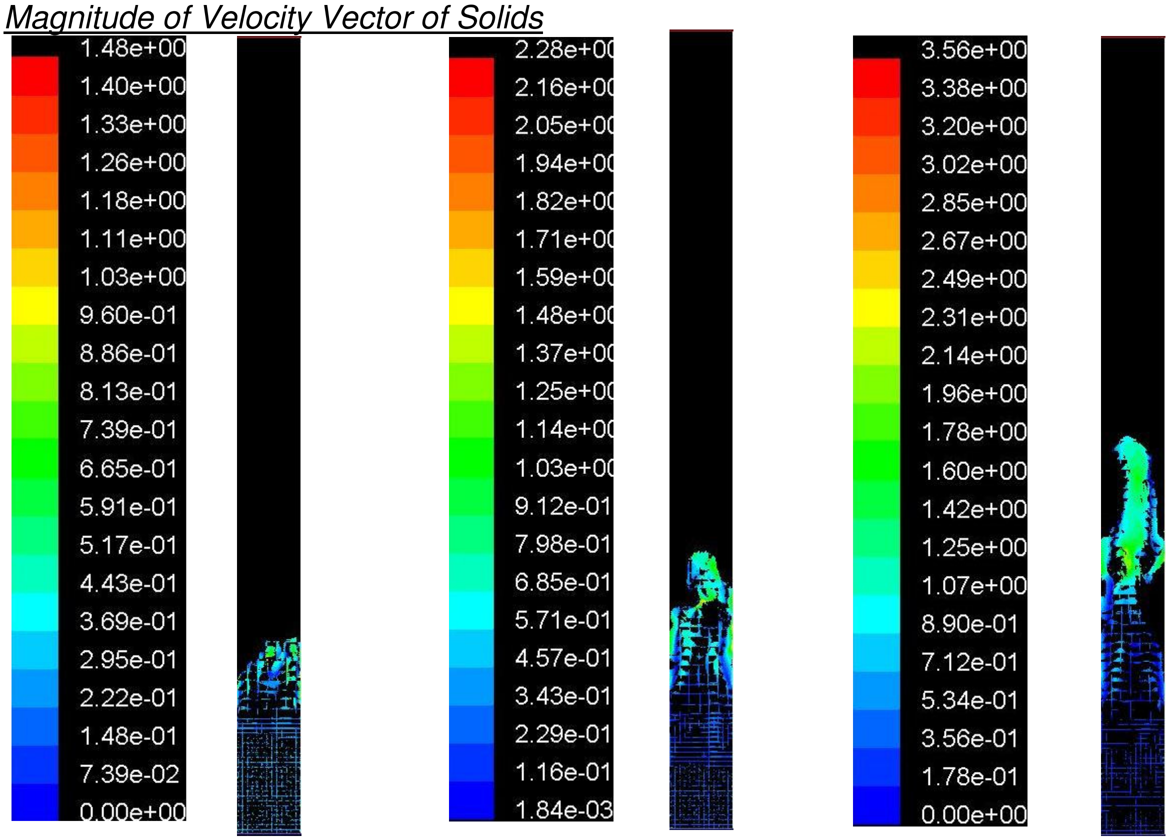


Fig-6.53 t=0.6s t= 0.9s t=1.5s

Three-phase Iron-ore 0.127m/s liquid-velocity & 0.05m/s gas-velocity-

Contours of Solid Volume fraction

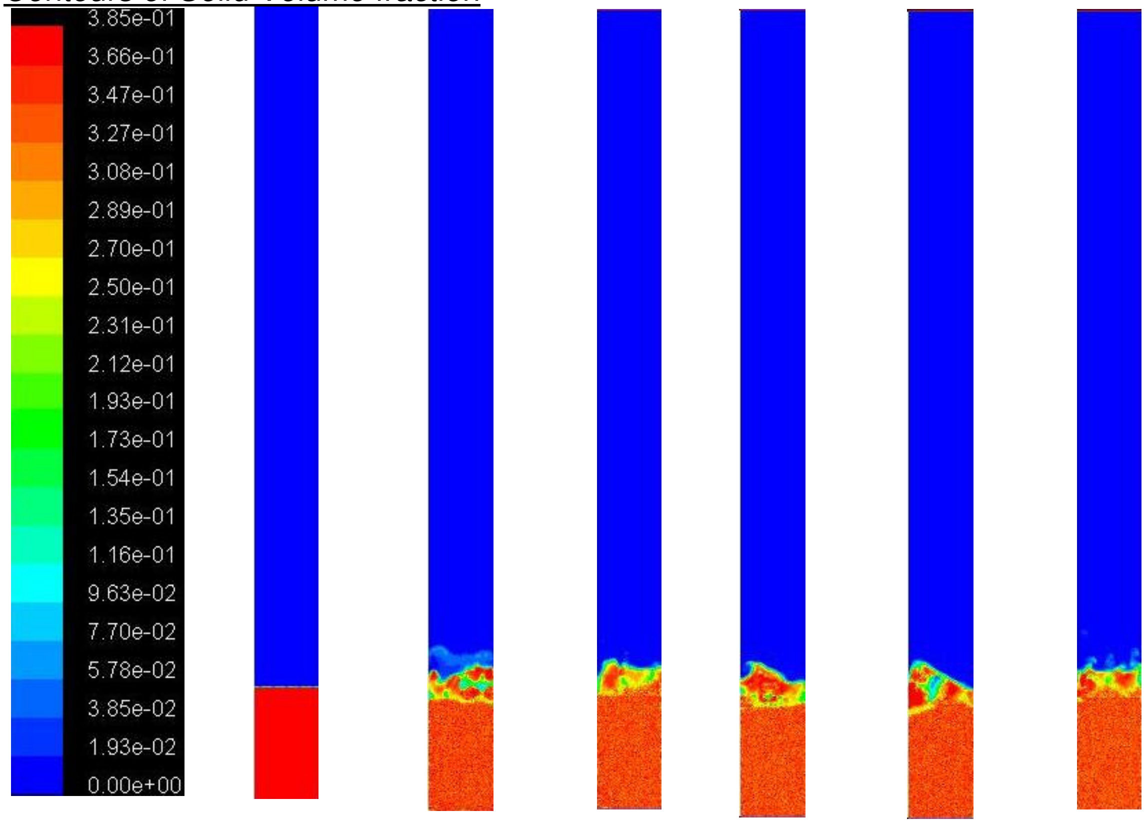


Fig-6.54 t= 0s 0.2s 0.4s 0.6s 0.8s 1s

Contours of Liquid Volume fraction

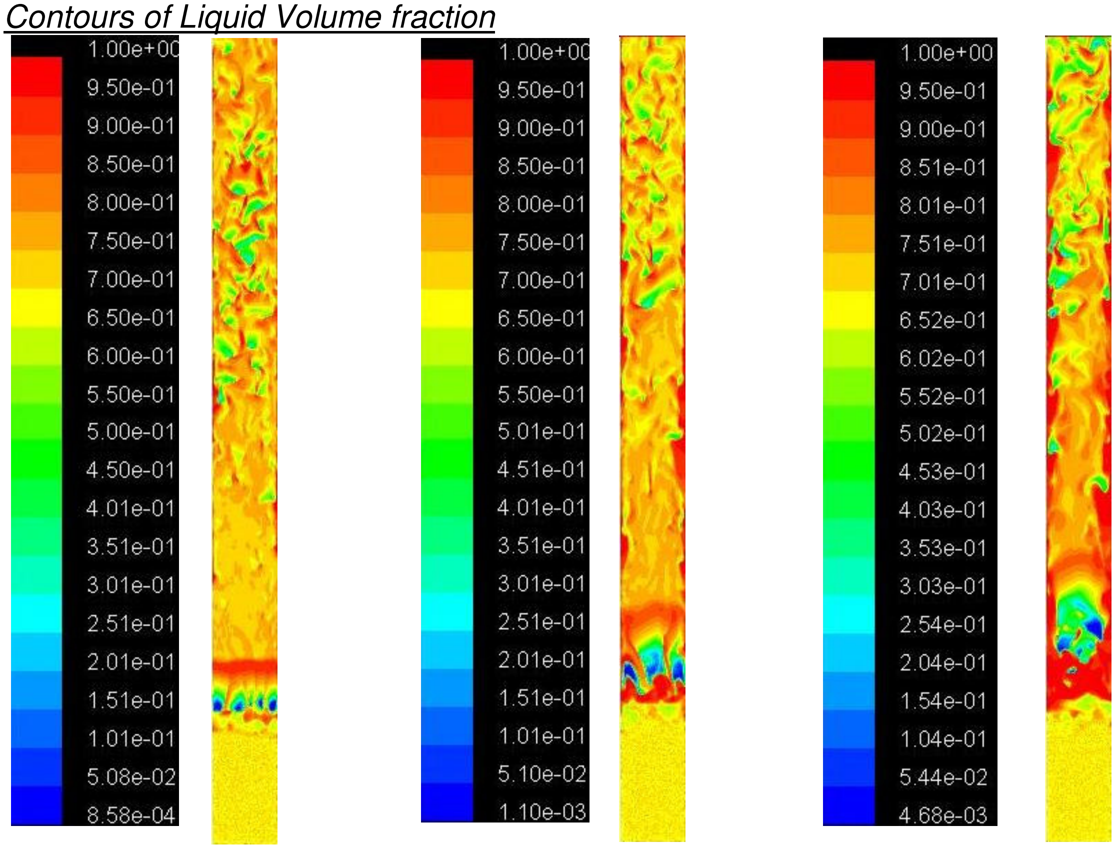


Fig-6.55 t=0.4s t= 0.8s t= 1s

Contours of Gas Volume fraction

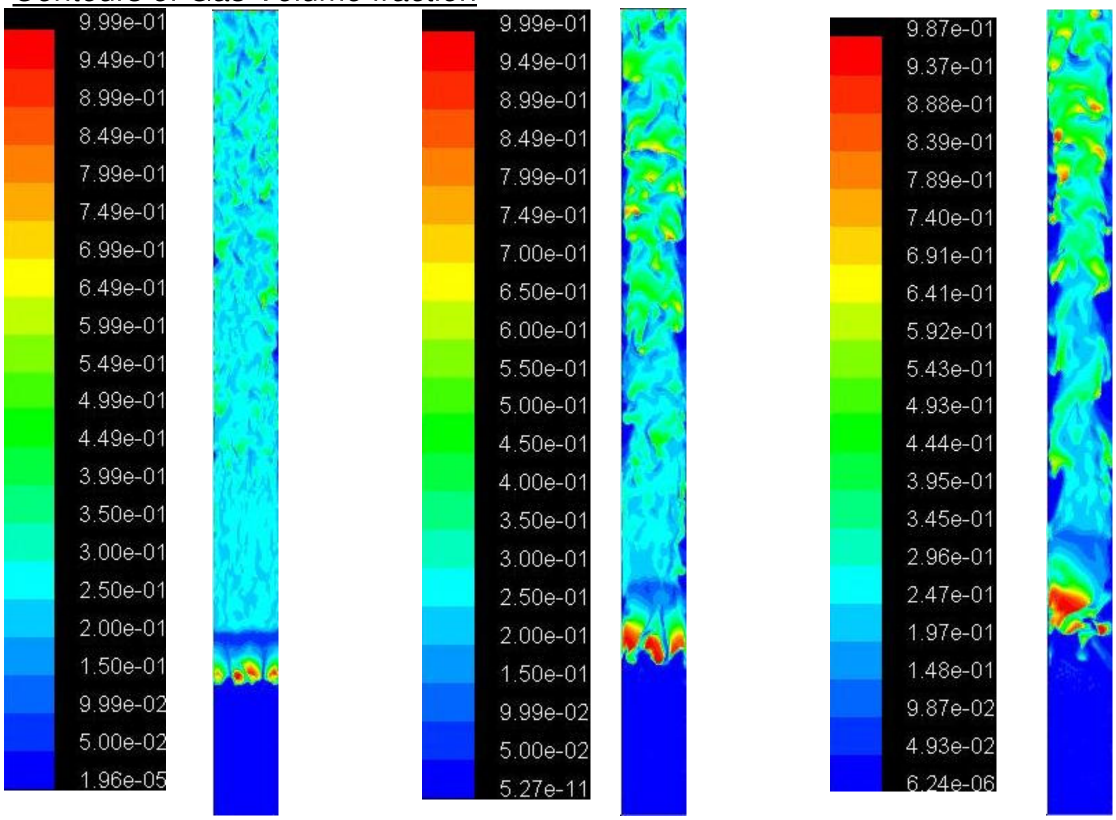


Fig-6.56 t=0.4s t= 0.8s t= 1s

C*ontours of Absolute Pressure(mixture) (Pascal)*

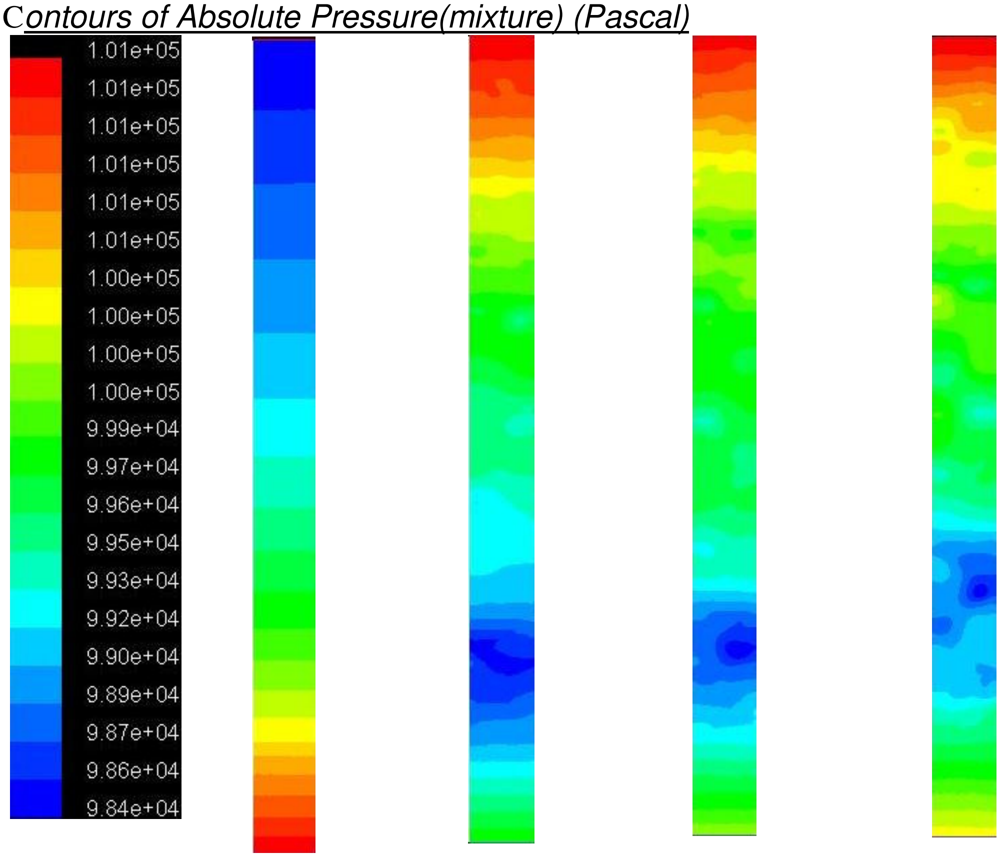
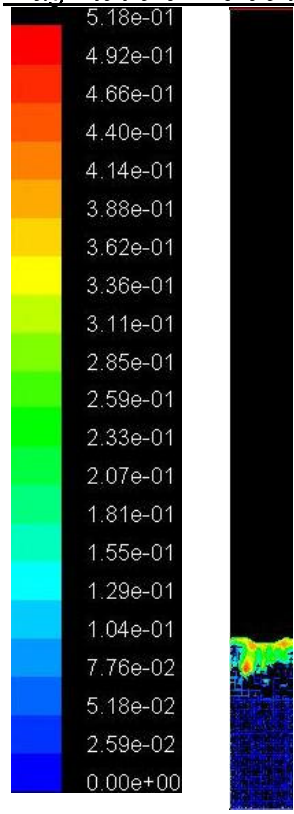
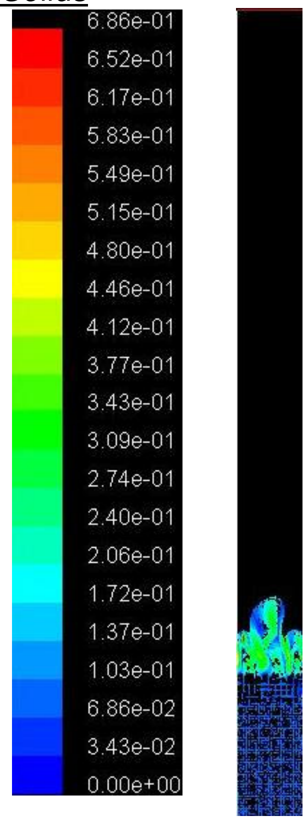


Fig-6.57 t= 0s 0.4s 0.8s 1s

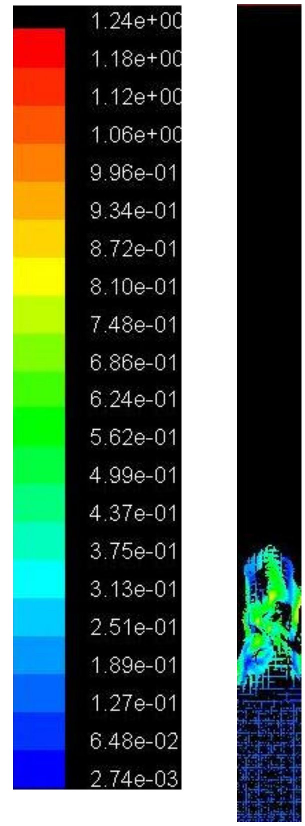
Magnitude of Velocity Vector of Solids



t=0.2s



t= 0.4s



t= 0.8s

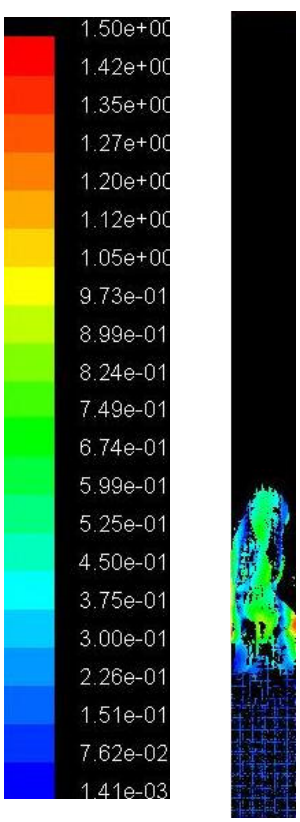


Fig-6.58 t=1s

Three-phase Coal 0.0425m/s liquid-velocity & 0.05m/s gas-velocity-

Contours of Solid Volume fraction

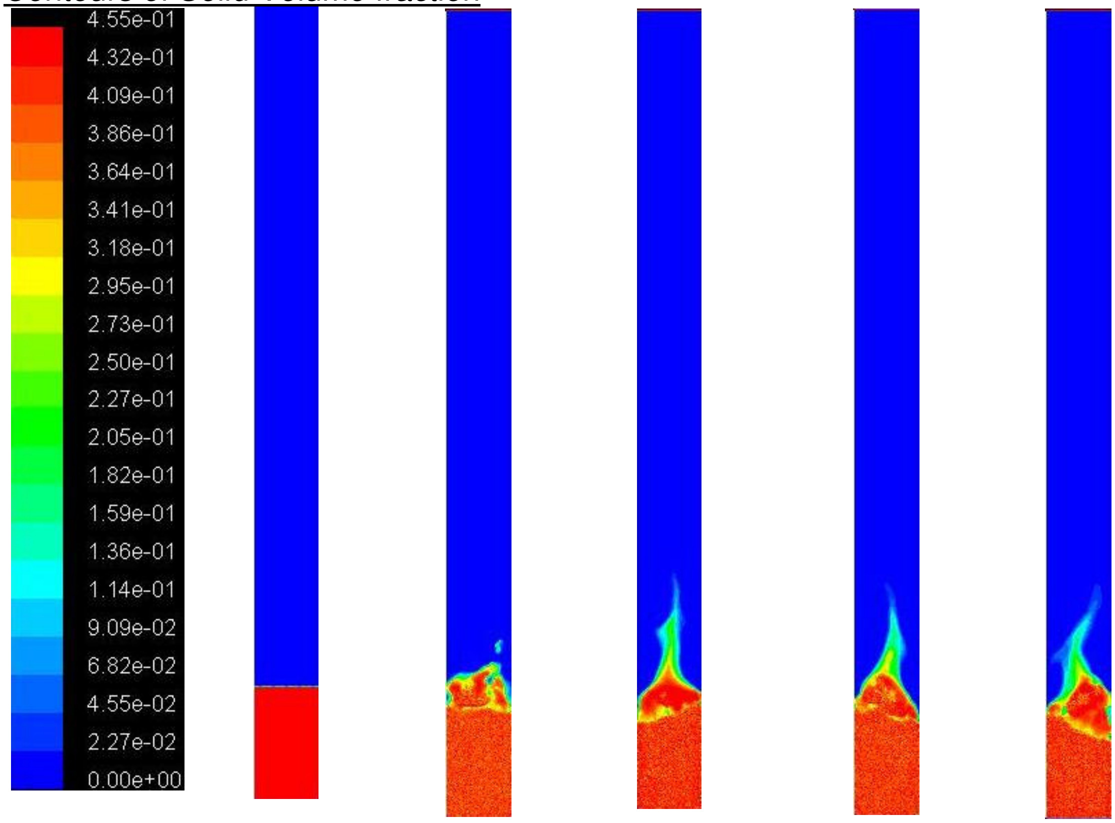


Fig-6.59 t= 0s 0.4s 0.8s 1.2s 1.6s

Contours of Liquid Volume fraction

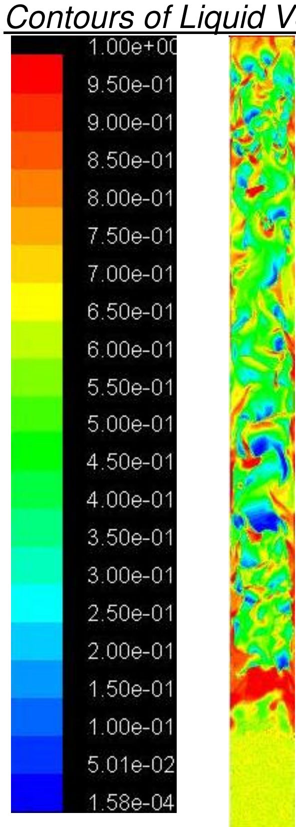


Fig-6.60 t=1.6s

Contours of Gas Volume fraction

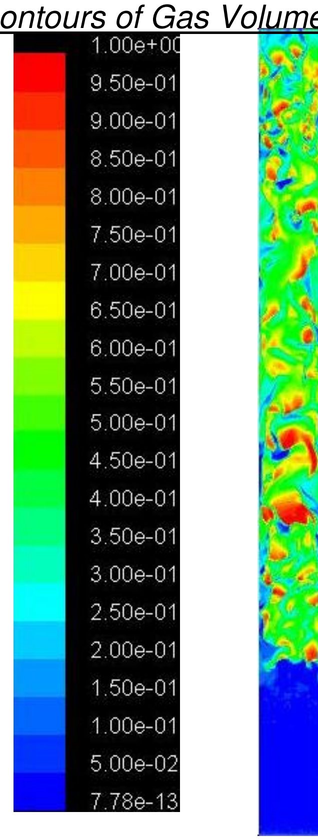


fig-6.61 t=1.6s

Contours of Absolute Pressure(mixture) (Pascal)

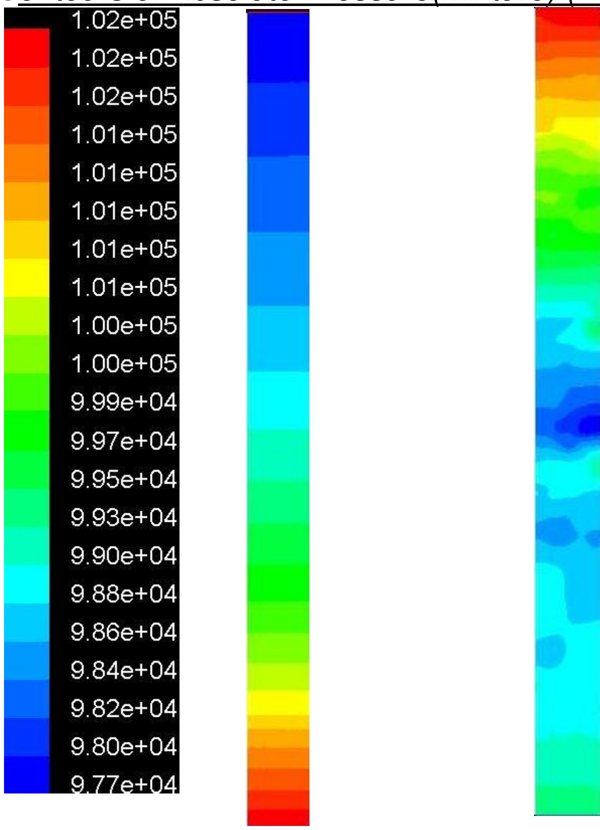


Fig-6.62 t=0s 1.6s

Magnitude of Velocity Vector of Solids

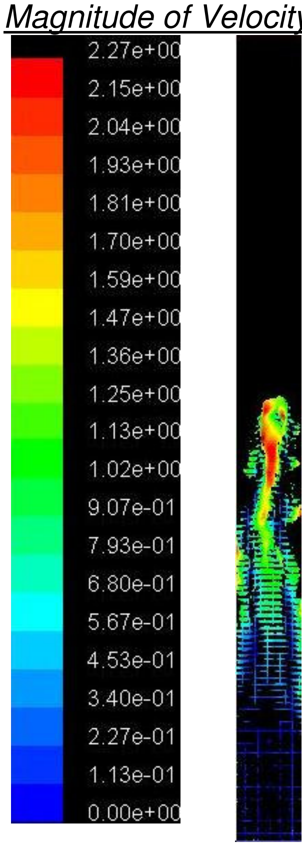


Fig-6.63 t=1.6s

Three-phase Dolomite 0.106m/s liquid-velocity & 0.05m/s gas-velocity-

Contours of Solid Volume fraction

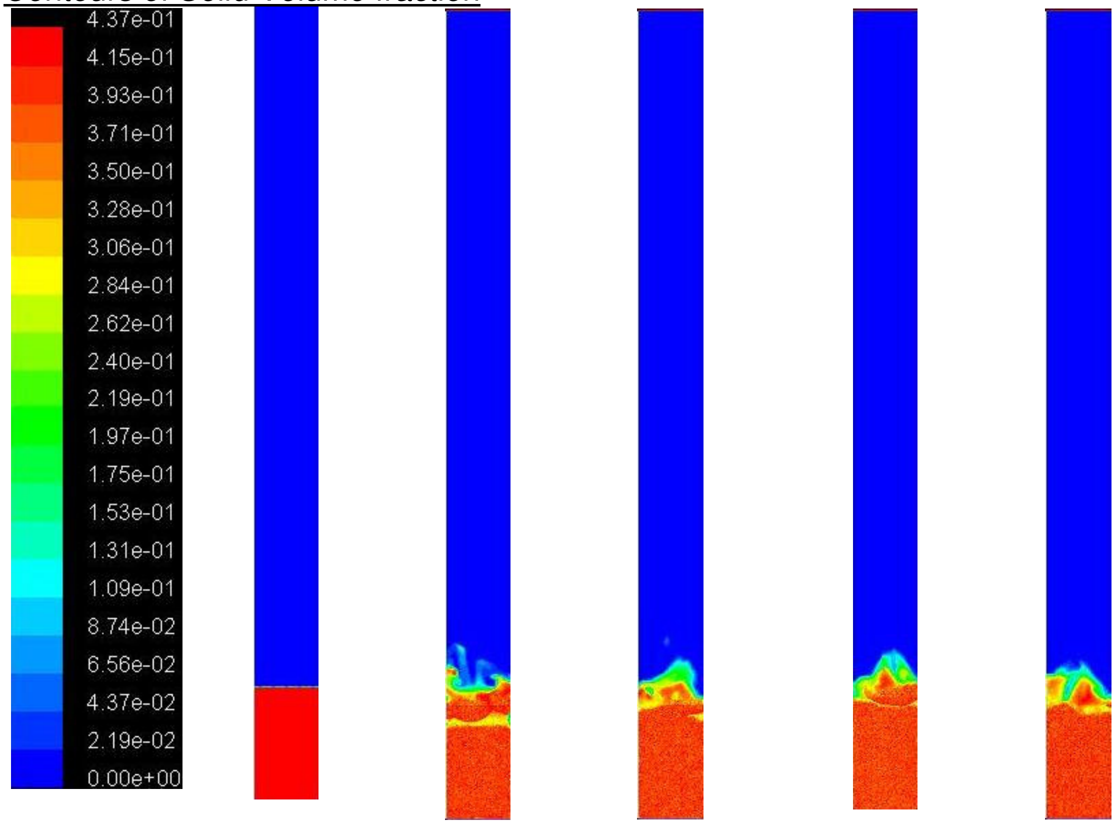


Fig-6.64 t= 0s 2s 4s 8s 10s

Contours of Liquid Volume fraction

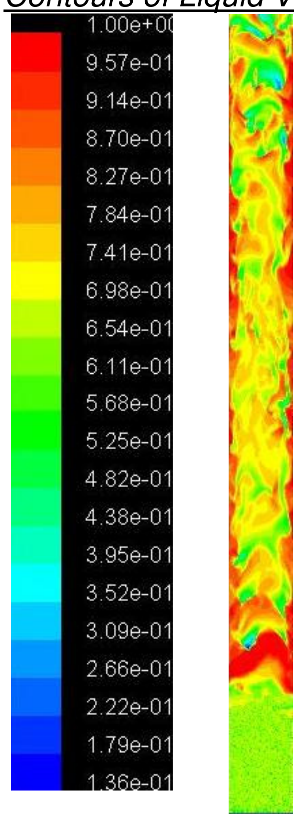


Fig-6.65 t=10s

Contours of Gas Volume fraction

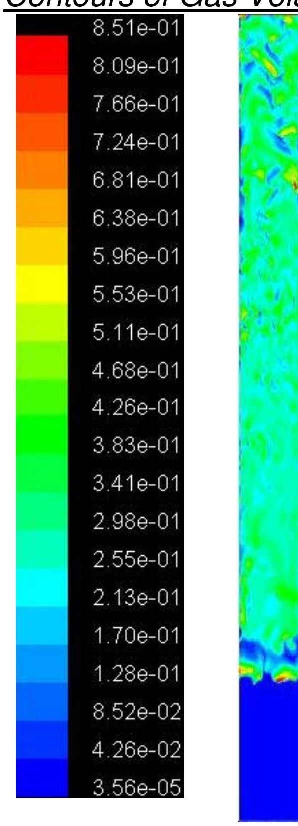


fig-6.66 t=10s

Contours of Absolute Pressure(mixture) (Pascal)

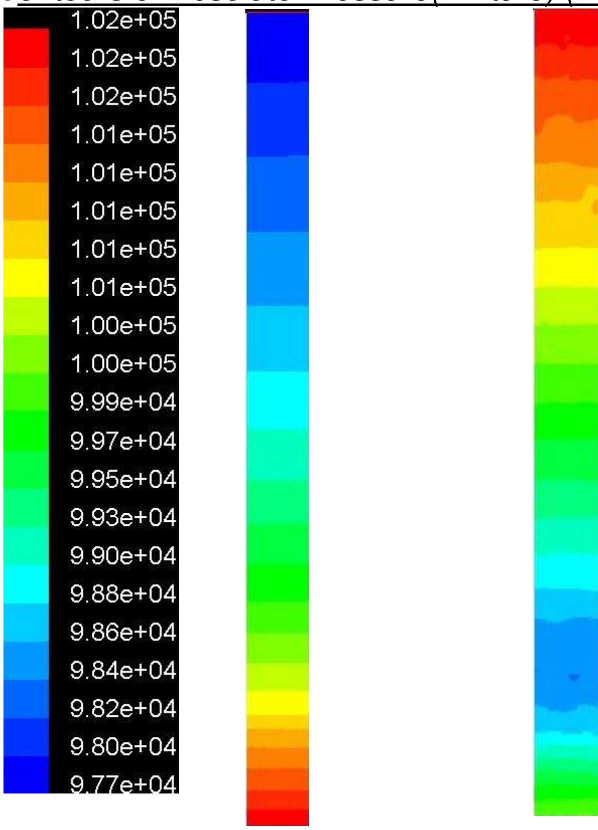


Fig-6.67 t= 0s 10s

Magnitude of Velocity Vector of Solids

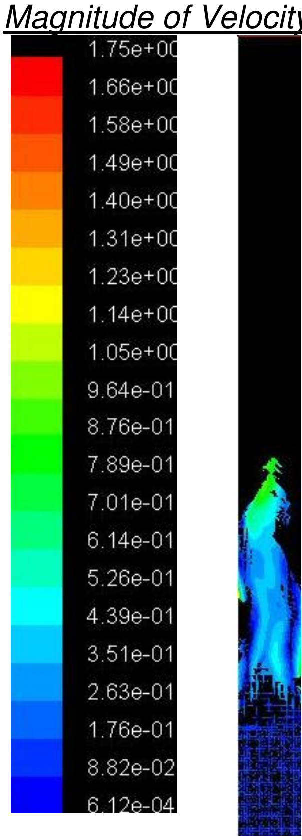


Fig-6.68 t=10s

Two-phase ;24%(w/w)Glycerol solution; 0.038m/s U_L-

Contours of Solid Volume fraction

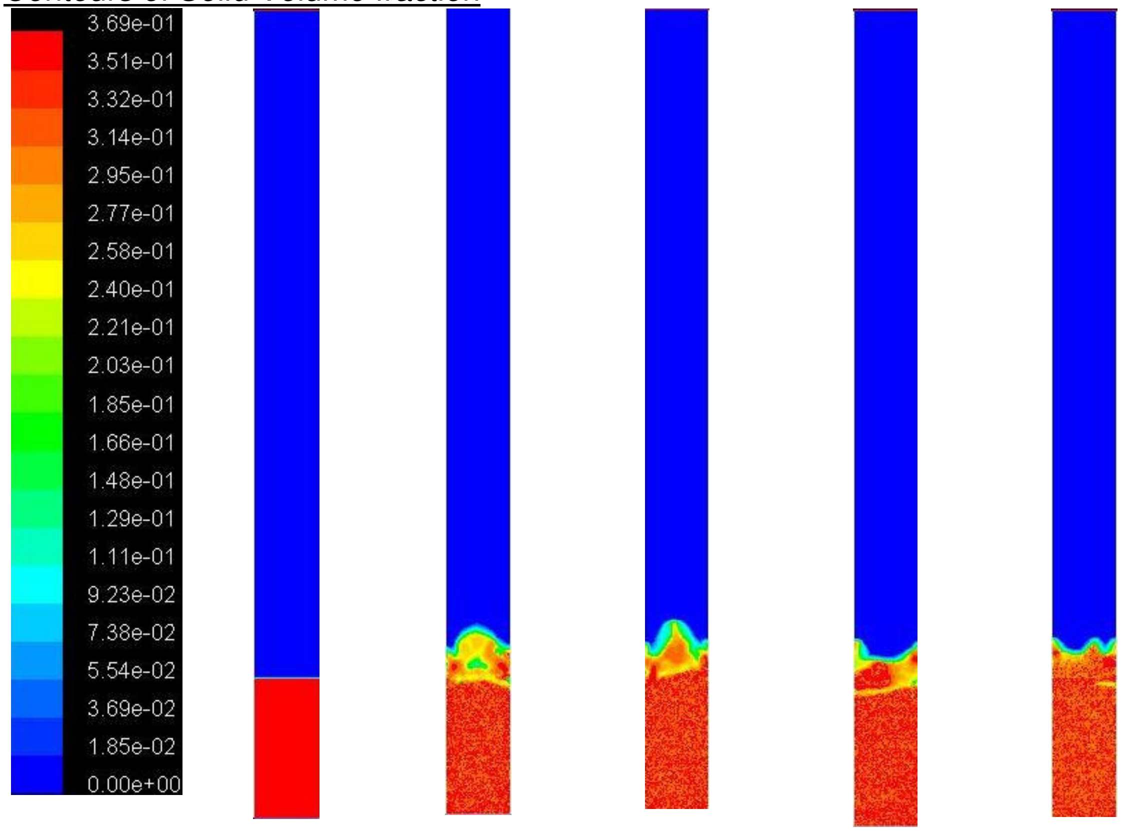


Fig-6.69 t=0s 1s 2s 3s 4s

Contours of Liquid Volume fraction

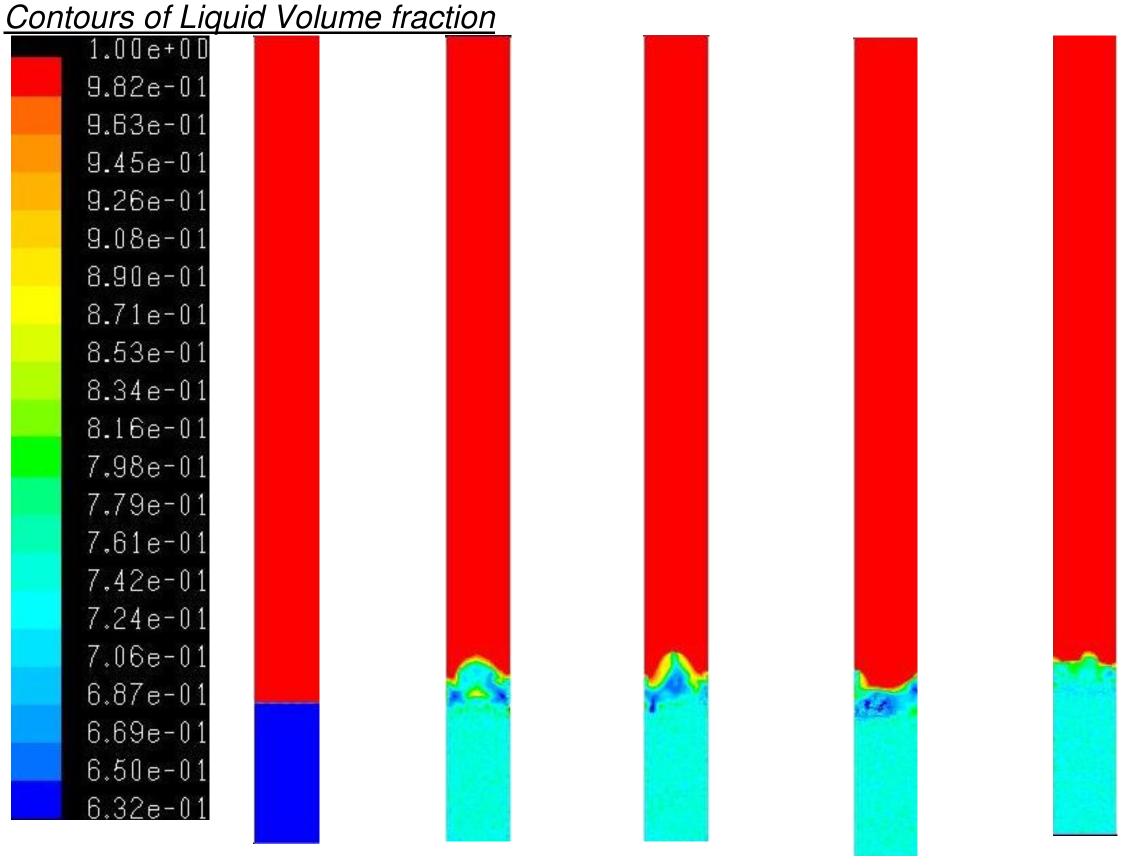


Fig-70 t=0s 1s 2s 3s 4s

C*ontours of Absolute Pressure(mixture) (Pascal)*

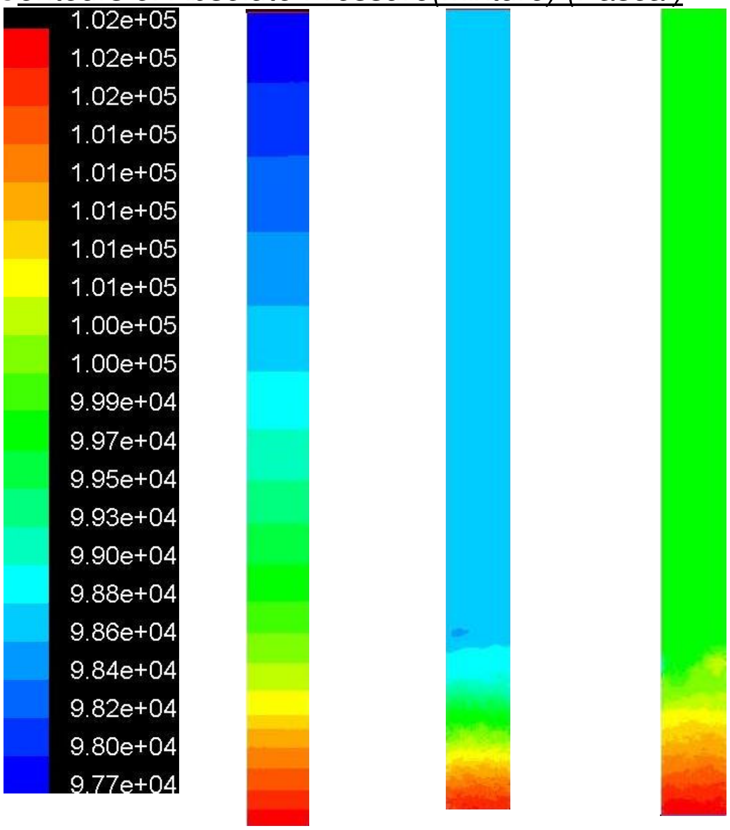


Fig-6.71 t= 0s 3s 4s

Magnitude of Velocity Vector of Solids

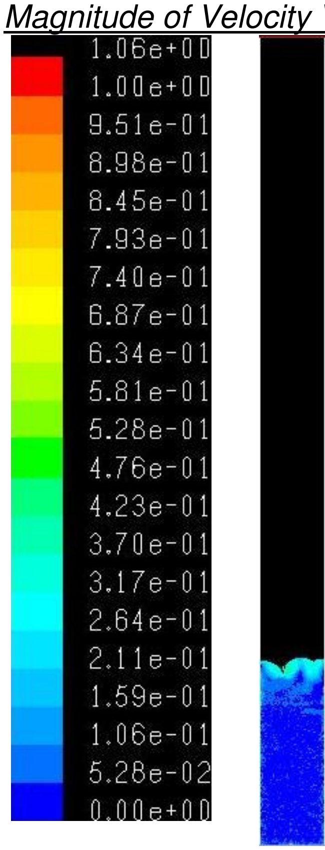


Fig-6.72 t=4s

Two-phase ;24%(w/w)Glycerol solution; 0.127m/s U_L-

Contours of Solid Volume fraction

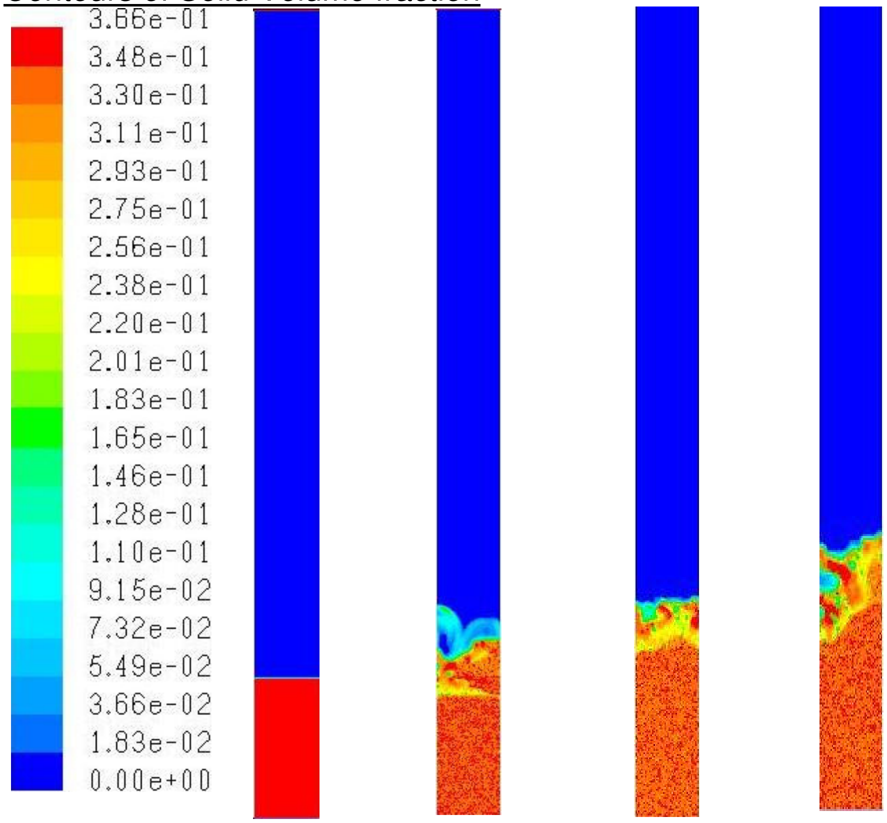


Fig-6.73 t= 0s 1s 3s 4s

Contours of Liquid Volume fraction

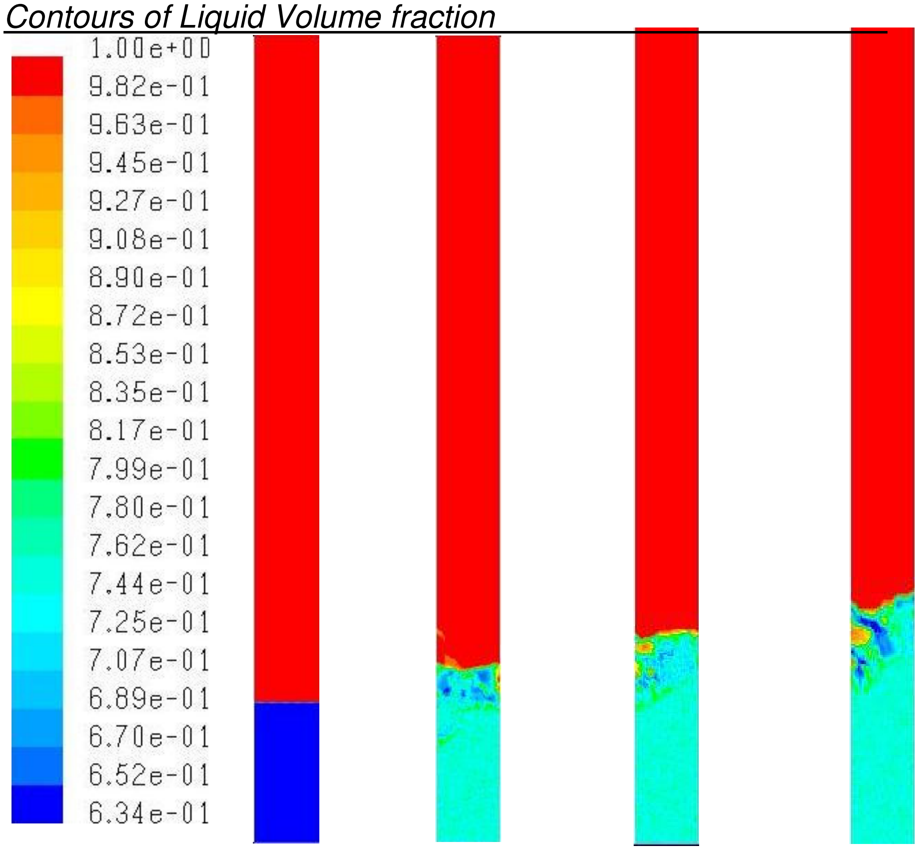


Fig-6.74 t= 0s 1s 3s 4s

Contours of Absolute Pressure(mixture) (Pascal)

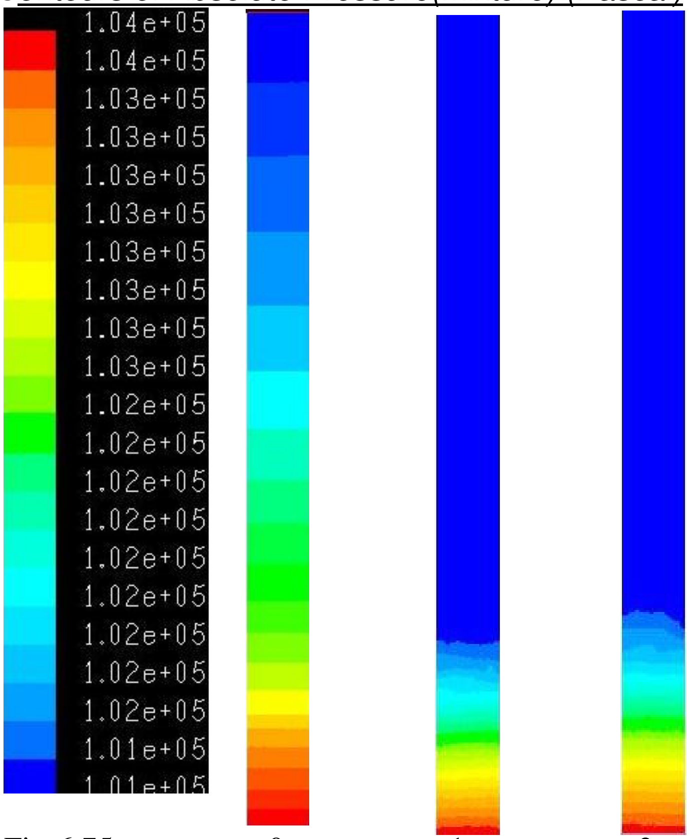


Fig-6.75 t=0s 1s 3s

Magnitude of Velocity Vector of Solids

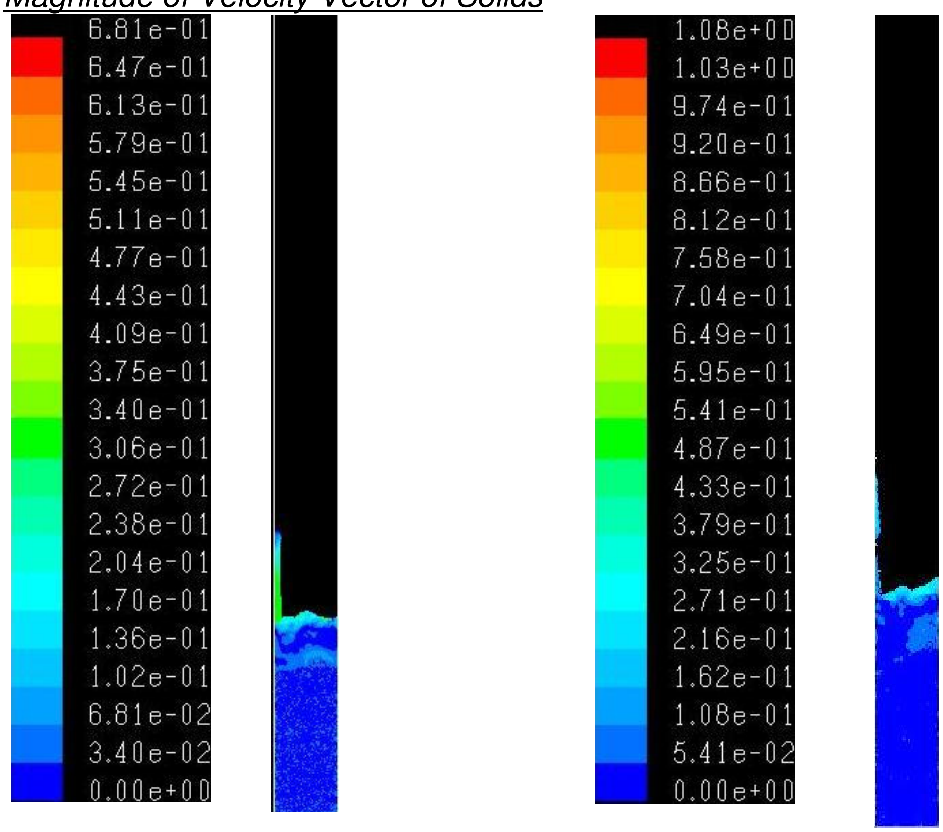


Fig-6.76 t=3s t=4s

Two-phase ;18%(w/w)Glycerol solution; 0.0404m/s U_L-

Contours of Solid Volume fraction

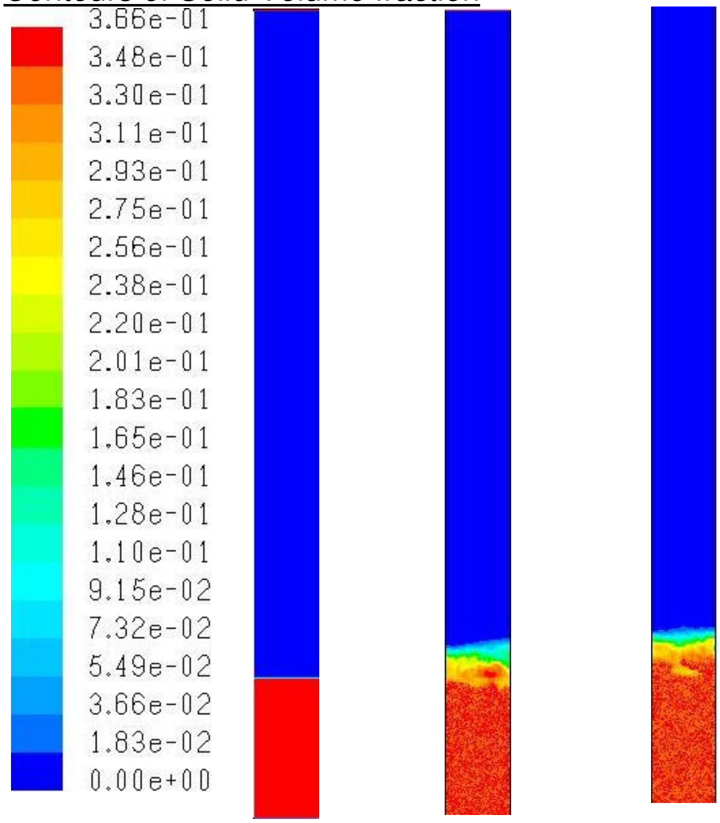


Fig-6.77 t=0s 2s 4s

Contours of Liquid Volume fraction

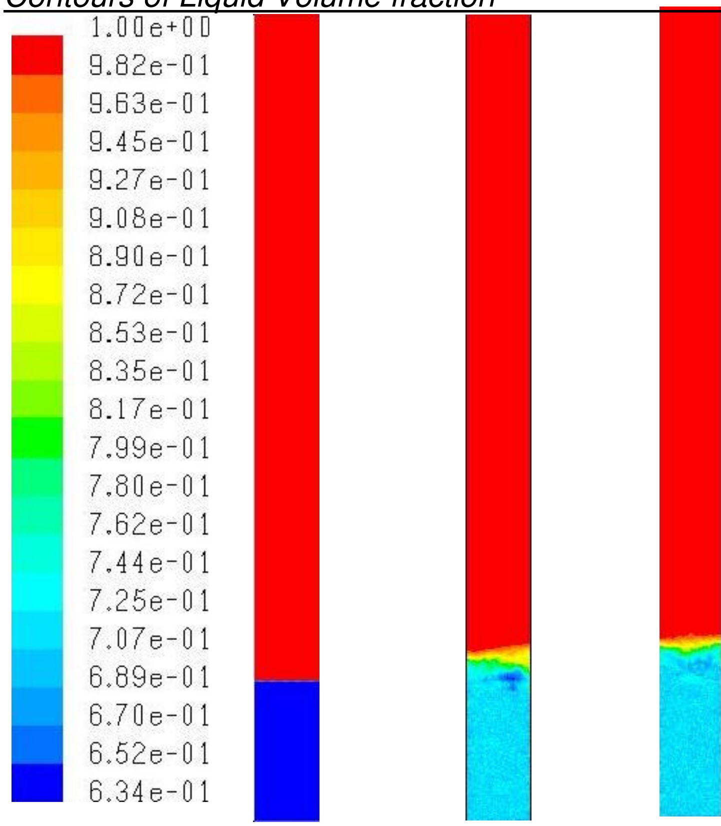


Fig-6.78 t=0s 2s 4s

Contours of Absolute Pressure(mixture) (Pascal)

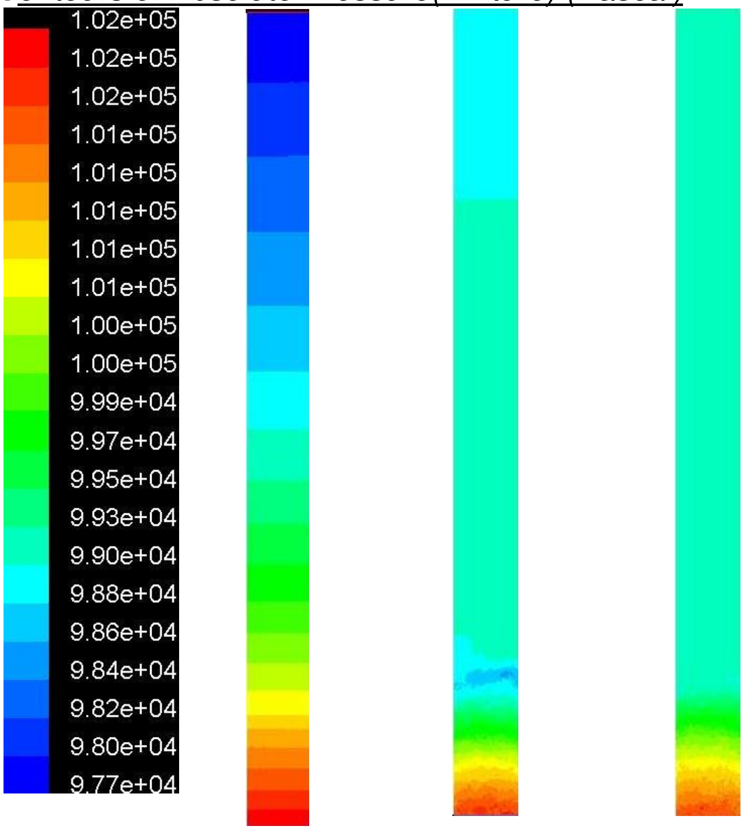


Fig-6.79 t=0s 2s 4s

Magnitude of Velocity Vector of Solids

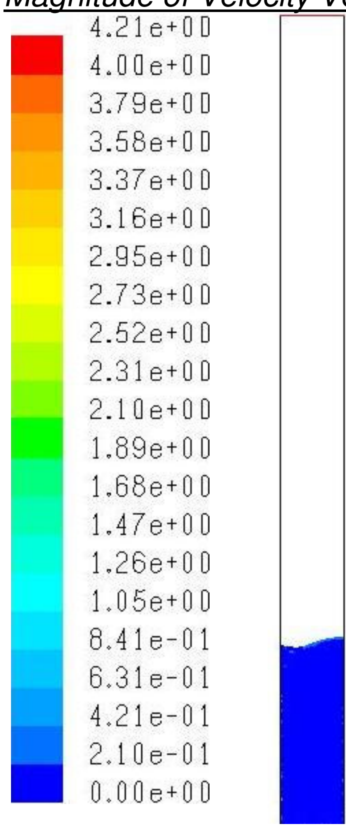


Fig-6.80 t=4s

<u>Two-phase ;18%(w/w)Glycerol solution; 0.127m/s U_L-</u>

Contours of Solid Volume fraction

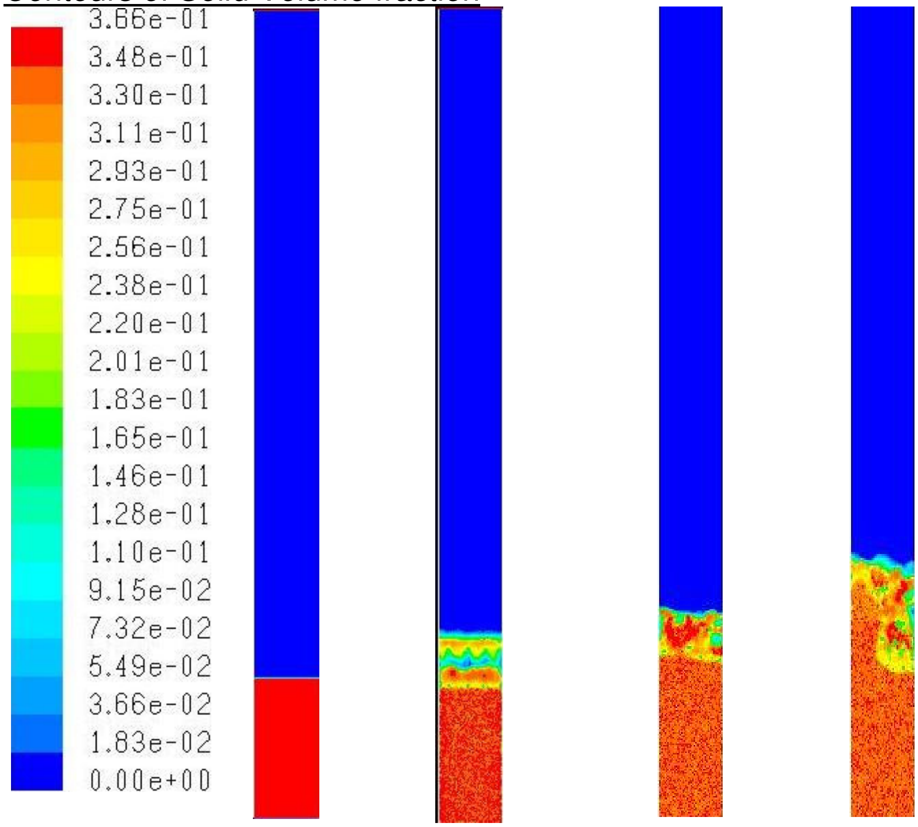


Fig-6.81 t=0s 0.5s 3s 4s

Contours of Liquid Volume fraction

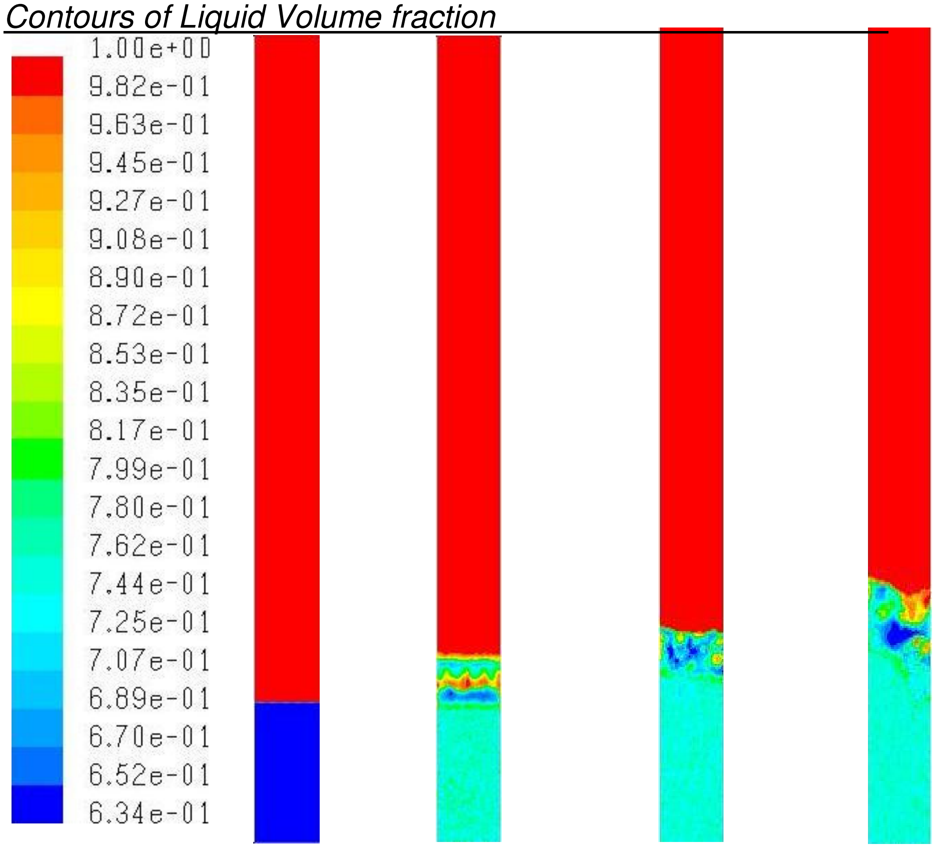


Fig-6.82 t=0s 0.5s 3s 4.5s

Contours of Absolute Pressure(mixture) (Pascal)

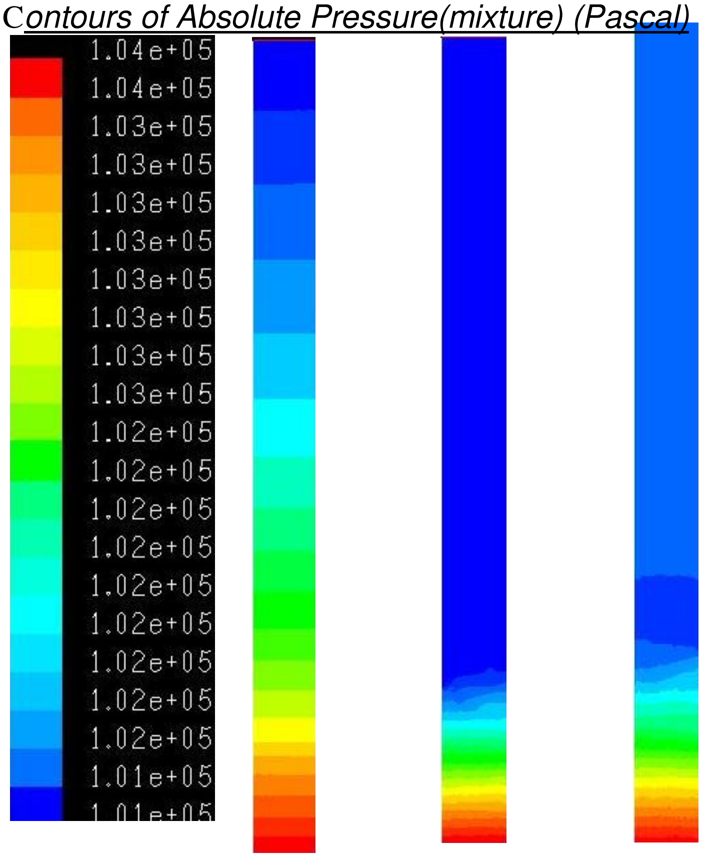


Fig-6.83 t= 0s 1.5s 3s

Magnitude of Velocity Vector of Solids

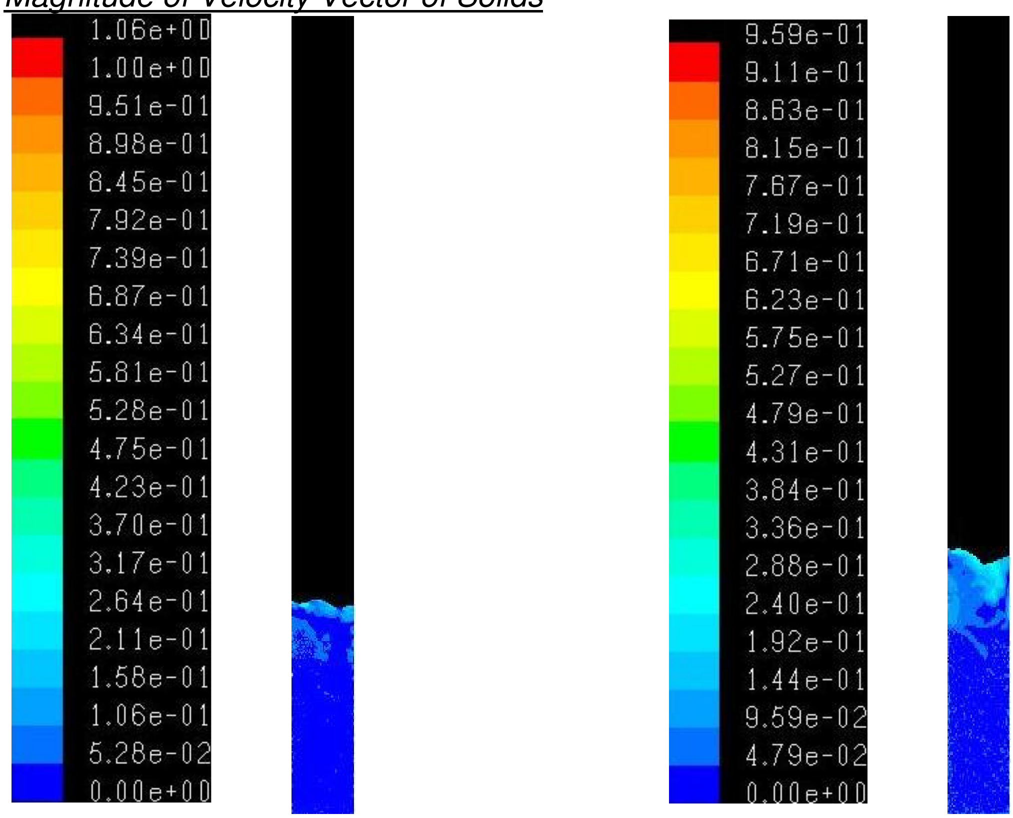


Fig-6.84 t=3s t=4.5s

Two-phase ;12%(w/w)Glycerol solution; 0.0404m/s U_L-

Contours of Solid Volume fraction

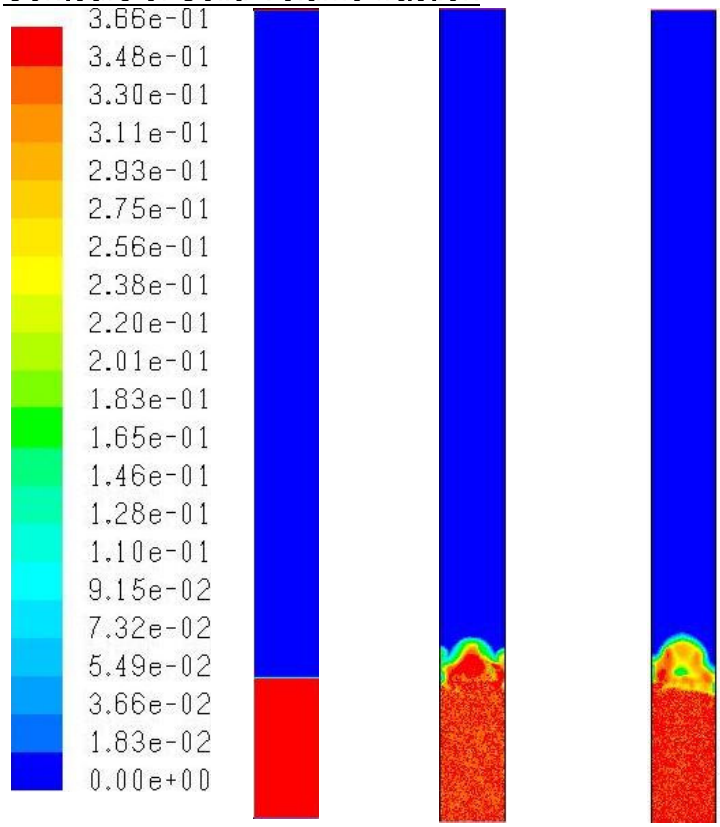


Fig-6.85 t=0s 2s 4s

Contours of Liquid Volume fraction

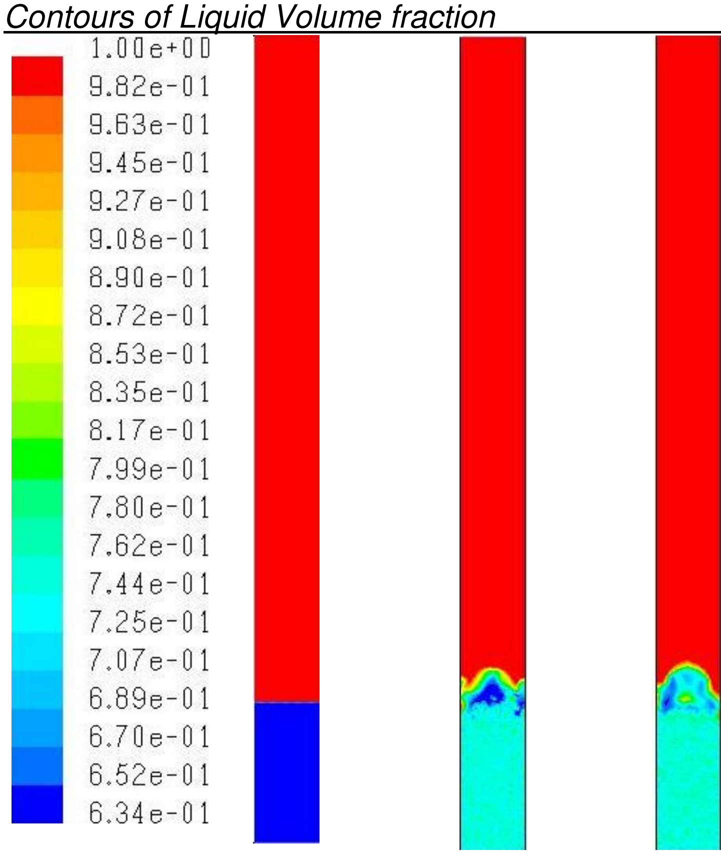


Fig-6.86 t=0s 2s 4s

Contours of Absolute Pressure(mixture) (Pascal)

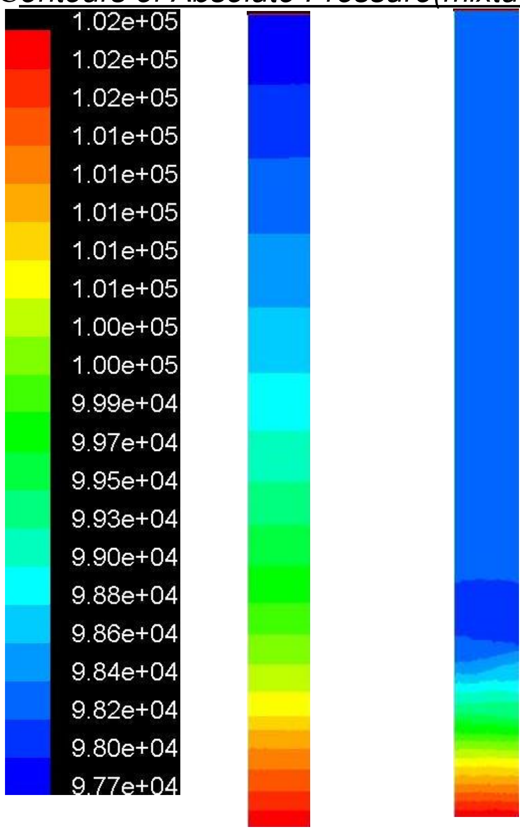


Fig-6.87 t=0s 4s

Magnitude of Velocity Vector of Solids

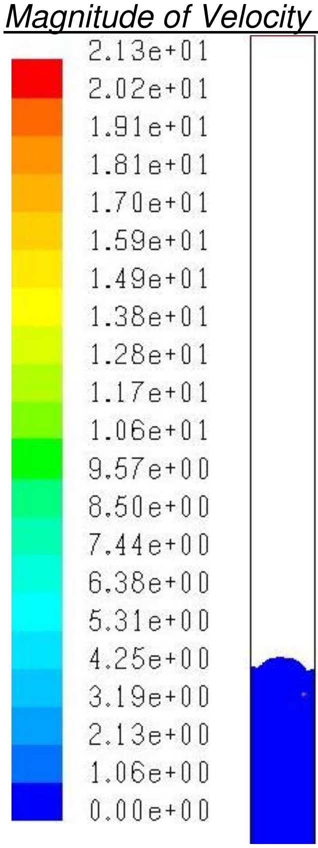


Fig-6.88 t=4s

Two-phase ;12%(w/w)Glycerol solution; 0.127m/s U_L-

Contours of Solid Volume fraction

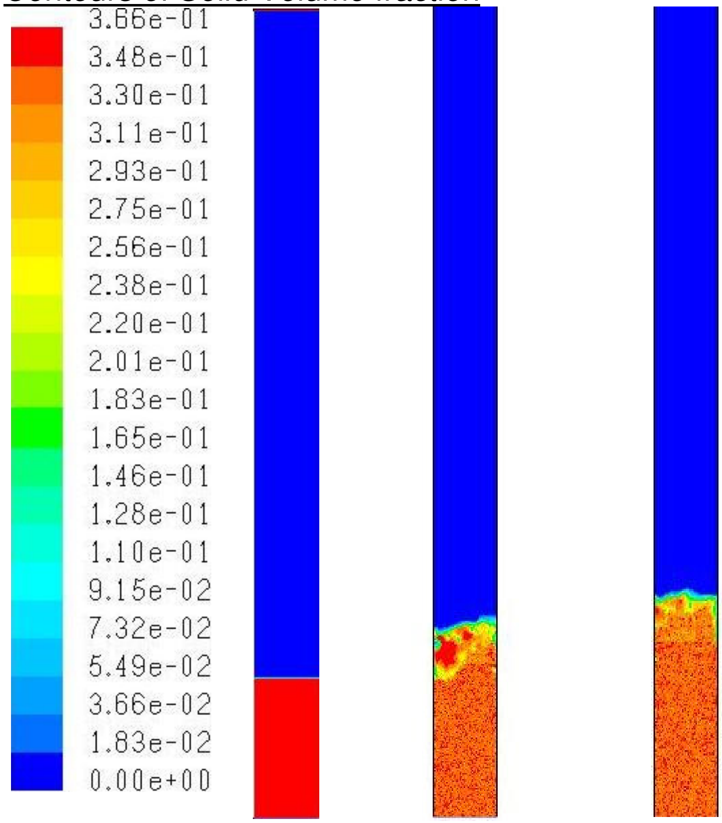


Fig-6.89 t=0s 1.5s 2.5s

Contours of Liquid Volume fraction

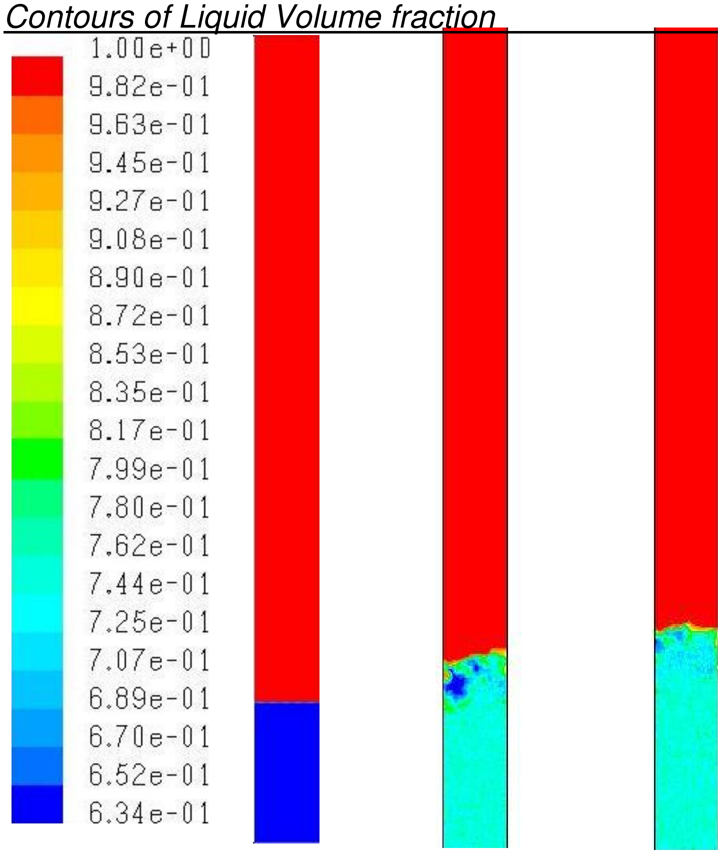


Fig6.90 t=0s 1.5s 2.5s

Contours of Absolute Pressure(mixture) (Pascal)

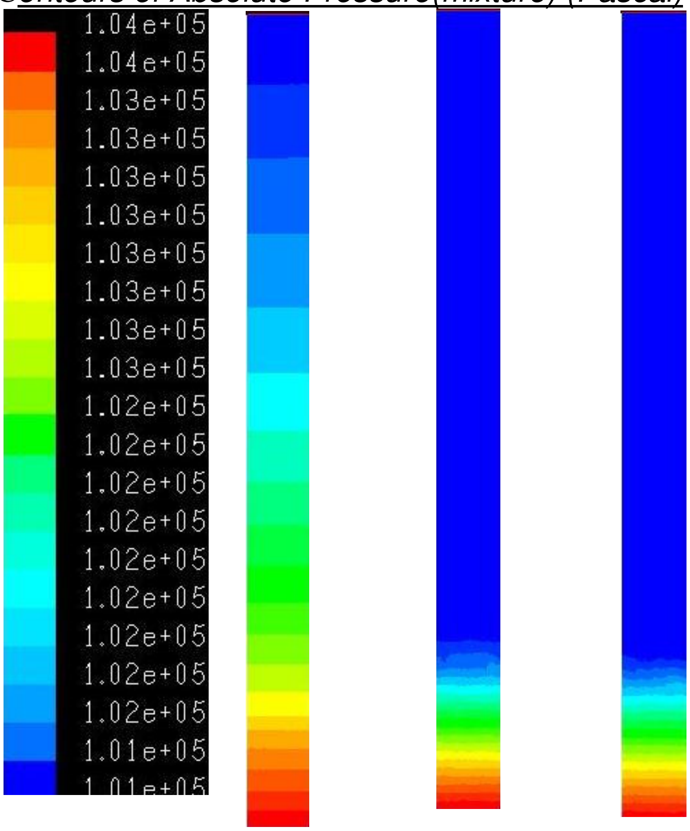


Fig-6.91 t=0s 1.5s 3s

Magnitude of Velocity Vector of Solids

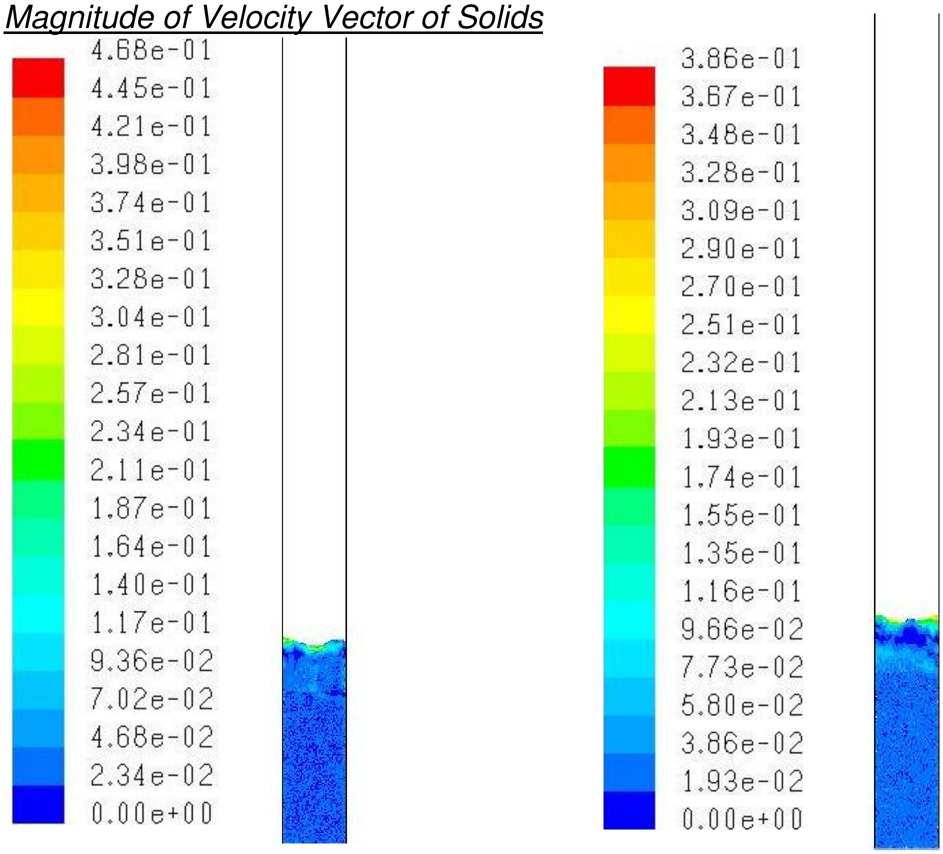


Fig-6.92 t=1.5s t=3s

Two-phase ;6%(w/w)Glycerol solution; 0.0425m/s U_L-

Contours of Solid Volume fraction

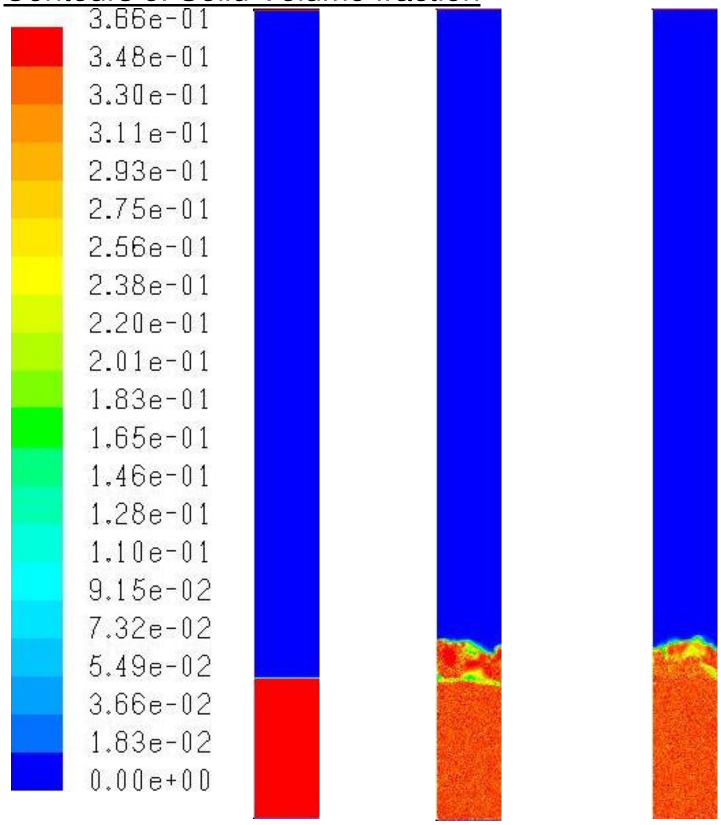


Fig-6.93 t=0s 3s 3.5s

Contours of Liquid Volume fraction

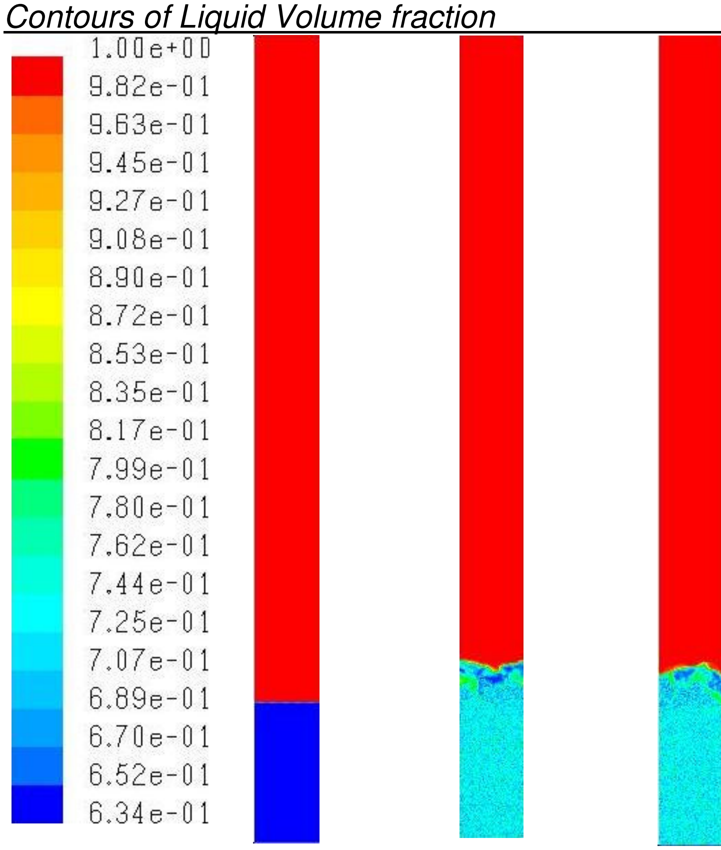


Fig-6.94 t= 0s 3s 3.5s

Contours of Absolute Pressure(mixture) (Pascal)

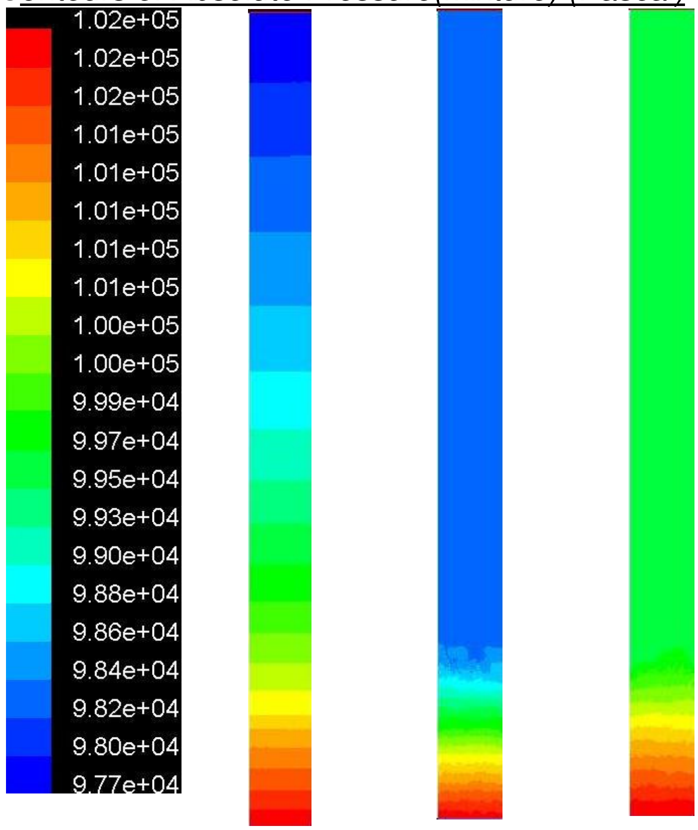


Fig-6.95 t=0s 3s 3.5s

Magnitude of Velocity Vector of Solids

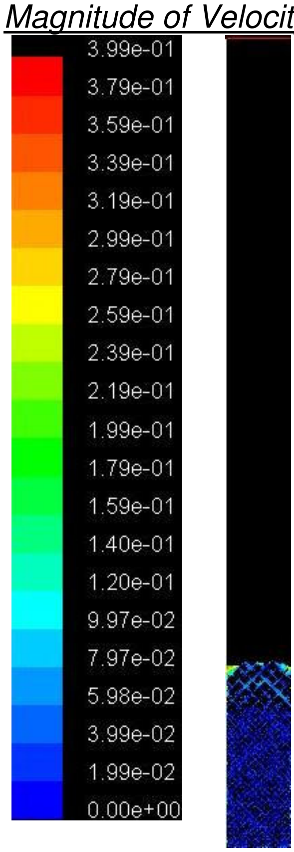


Fig-6.96 t=3.5s

<u>Two-phase ;6%(w/w)Glycerol solution; 0.127m/s U_L-</u>

<u>Contours of Solid Volume fraction</u>

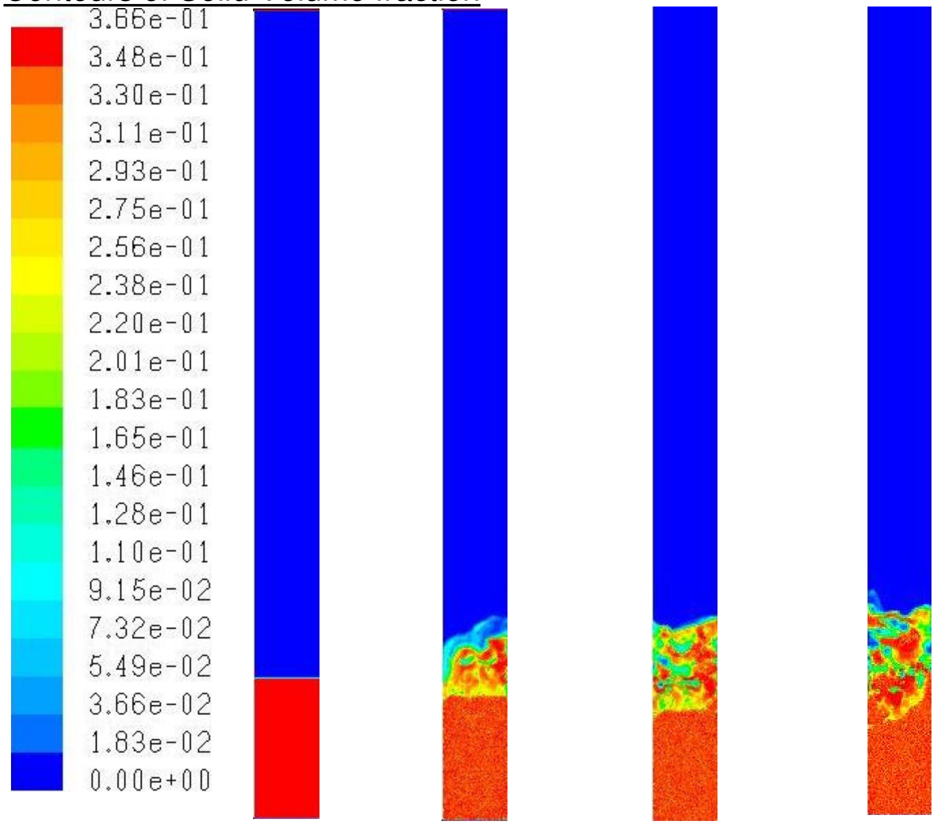


Fig-6.97 t=0s 1s 1.5s 3s

<u>Contours of Liquid Volume fraction</u>

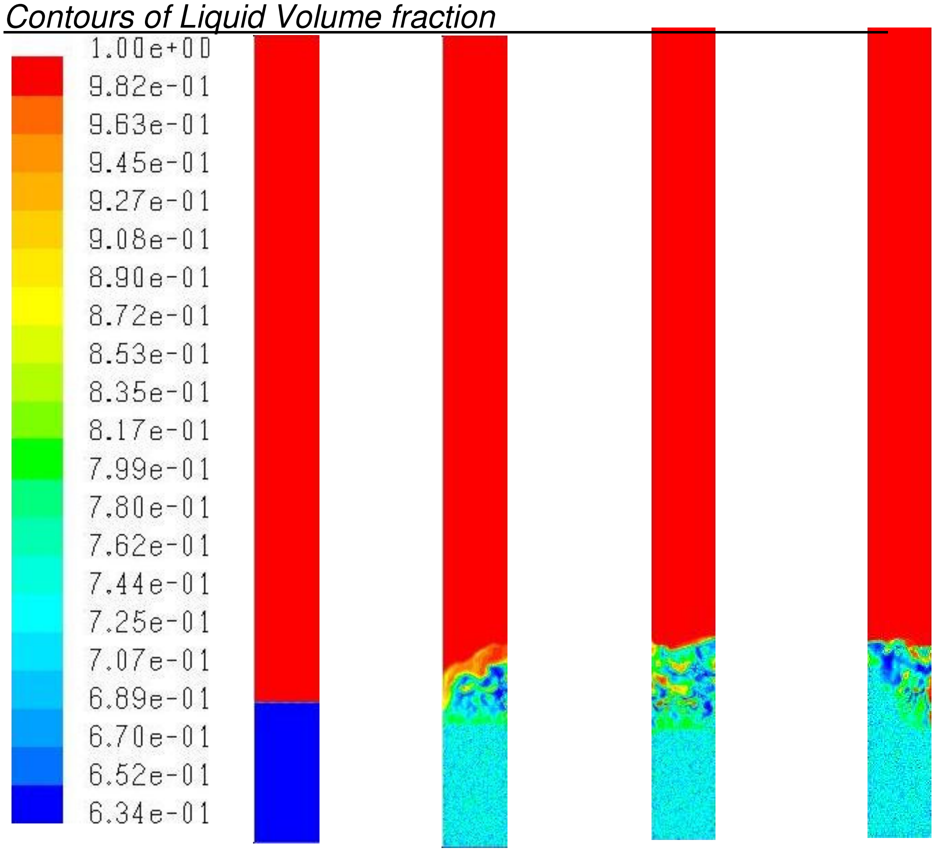


Fig-6.98 t=0s 1s 1.5s 3s

Contours of Absolute Pressure(mixture) (Pascal)

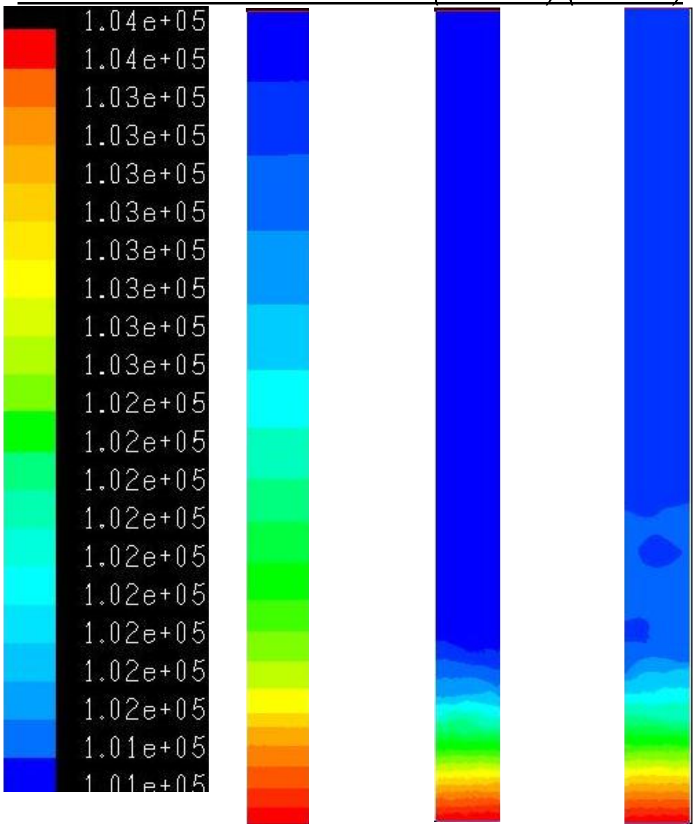


Fig-6.99 t= 0s 1.5s 3s

Magnitude of Velocity Vector of Solids

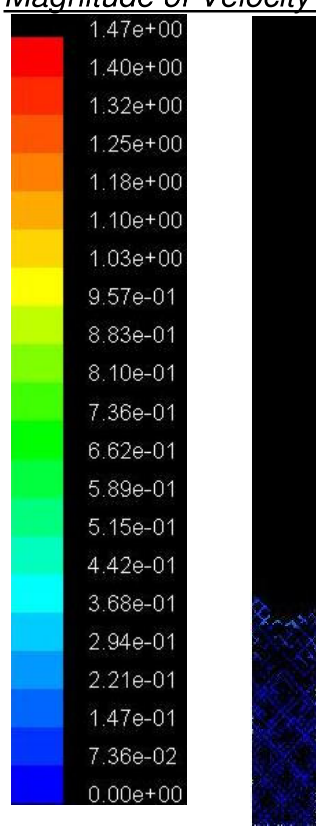


Fig-6.100 t=3s

Three-phase ;24%(w/w)Glycerol solution;0.085m/sU$_L$ & 0.051m/s U$_G$-

Contours of Solid Volume fraction

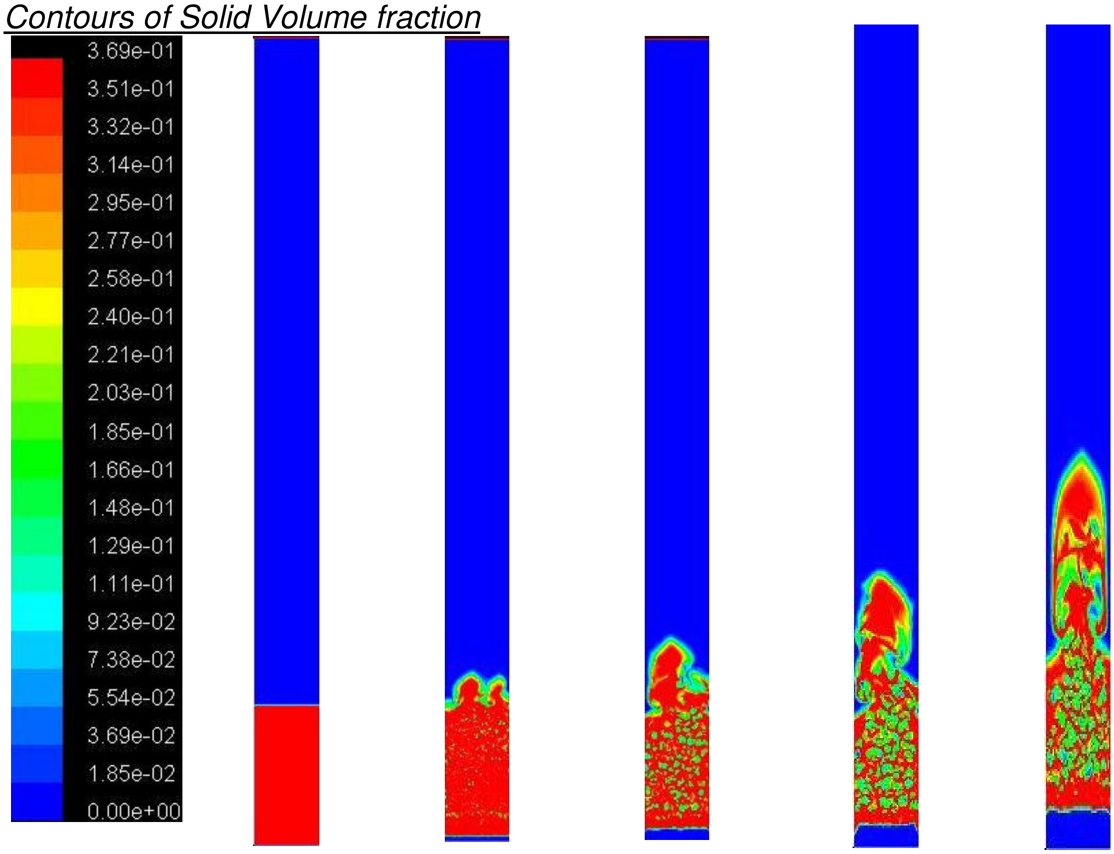


Fig-6.101 t= 0s 5s 10s 15s 20s

Contours of Liquid Volume fraction

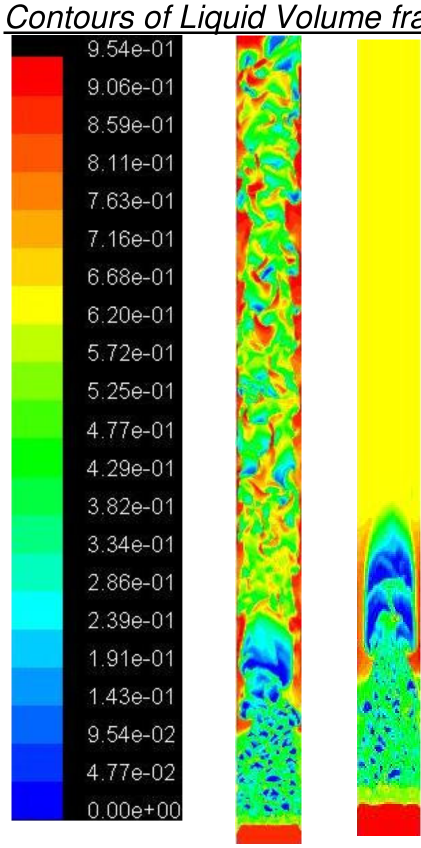


Fig-6.102 t= 15s 20s

Contours of Gas Volume fraction

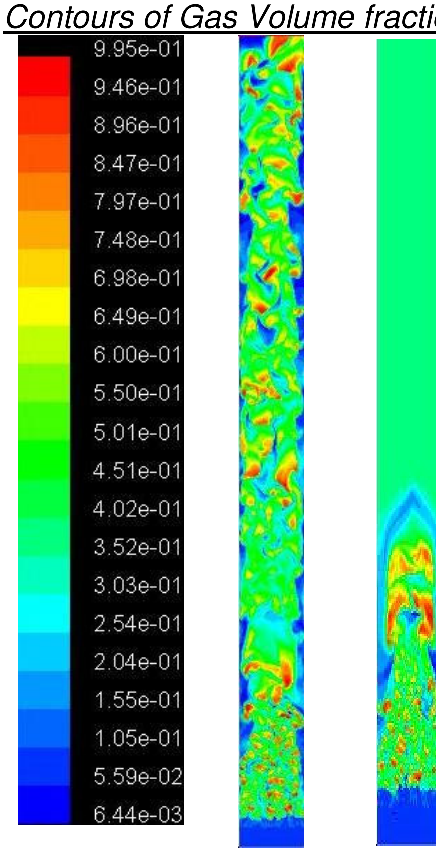


fig-6.103 t=15s 20s

Contours of Absolute Pressure(mixture) (Pascal)

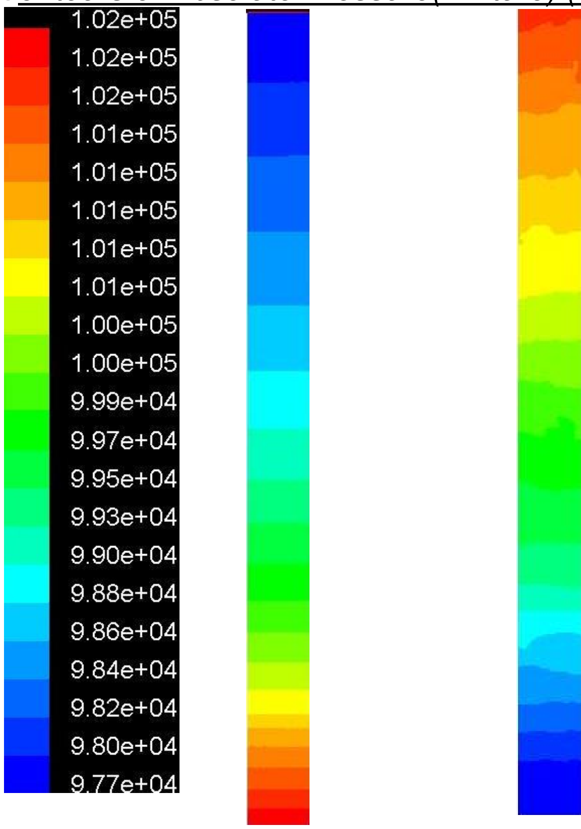


Fig-6.104 t=0s 20s

Magnitude of Velocity Vector of Solids

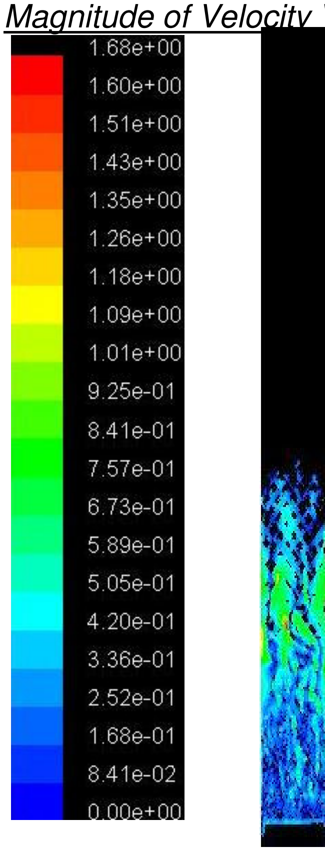


Fig-6.105 t=20s

Three-phase ;18%(w/w)Glecerol solutioncity;0.127m/sU$_L$ & 0.051m/s U$_G$-

Contours of Solid Volume fraction

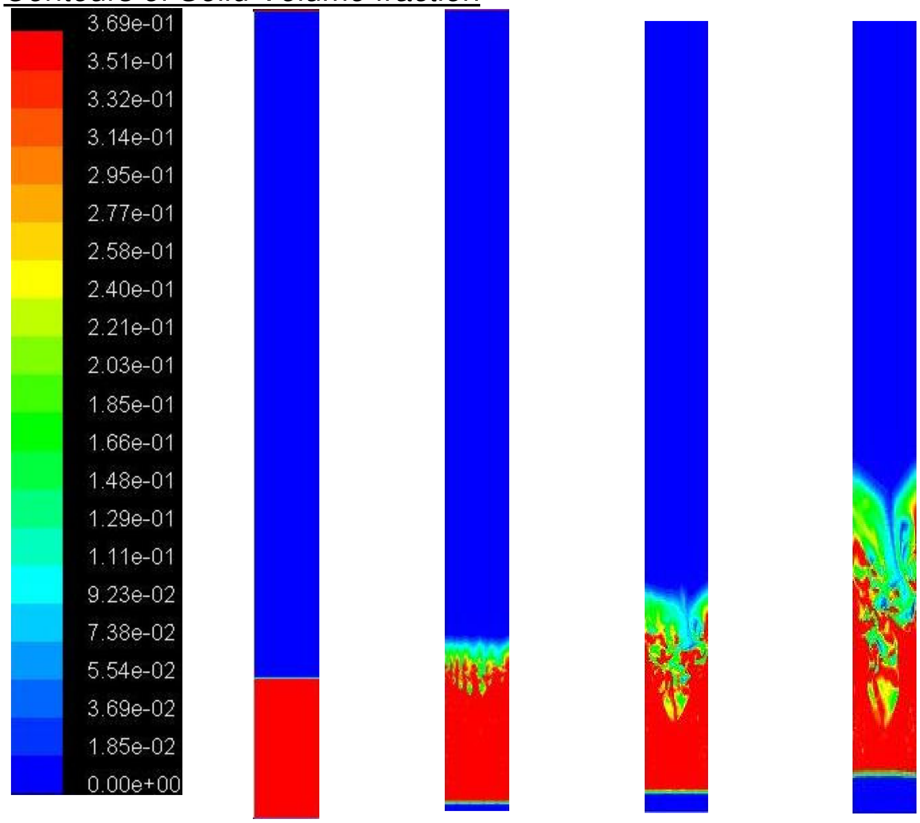


Fig-6.106 t=0s 5s 10s 15s

Contours of Liquid Volume fraction

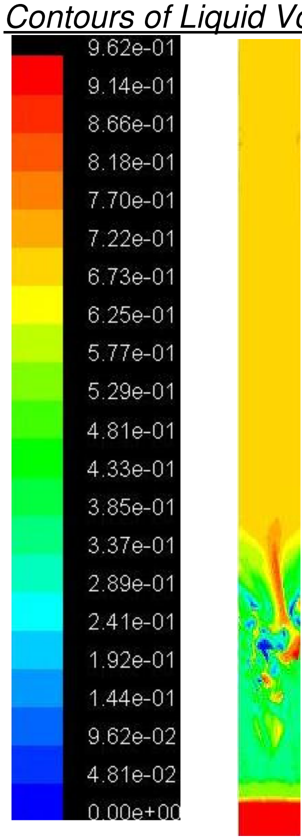


Fig-6.107 t=15s

Contours of Gas Volume fraction

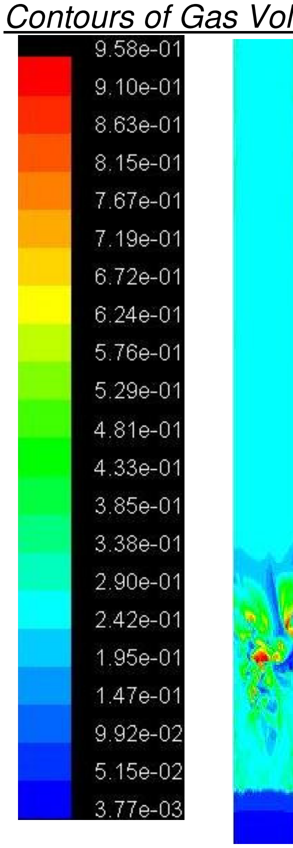


fig-6.108 t=15s

Contours of Absolute Pressure(mixture) (Pascal)

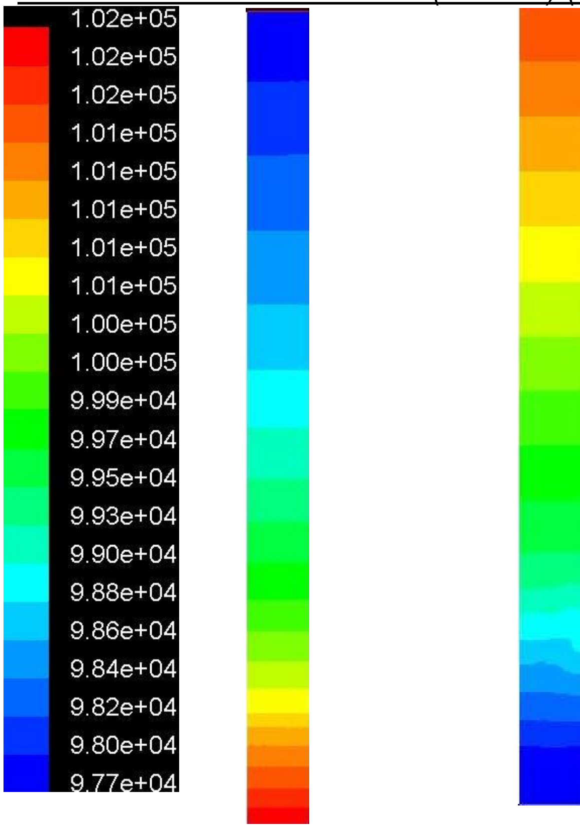


Fig-6.109 t=0s 20s

Magnitude of Velocity Vector of Solids

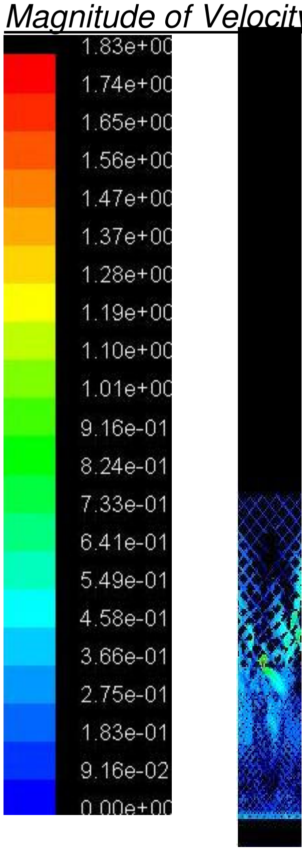


Fig-6.110 t=20s

Three-phase ;12%(w/w)Glecerol solutioncity;0.127m/sU$_L$ & 0.051m/s U$_G$-

Contours of Solid Volume fraction

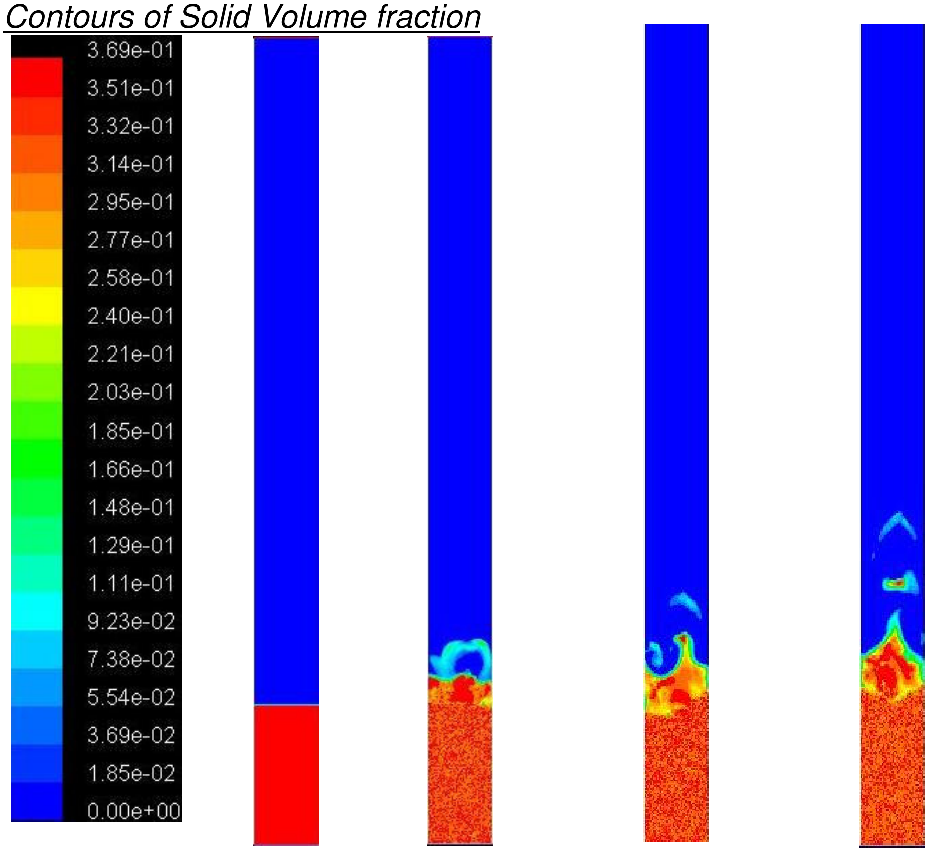


Fig-6.111 t= 0s 5s 10s 15s

Contours of Liquid Volume fraction

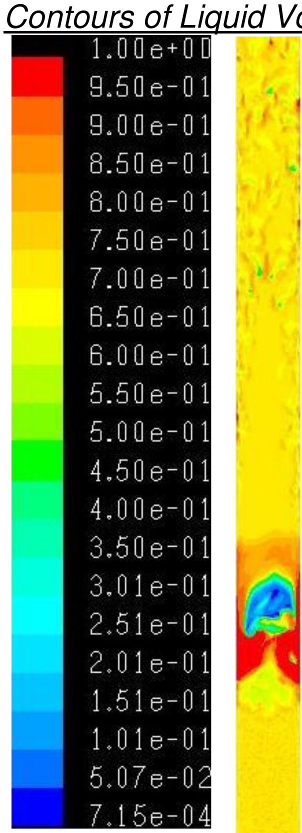


Fig-6.112 t=15s

Contours of Gas Volume fraction

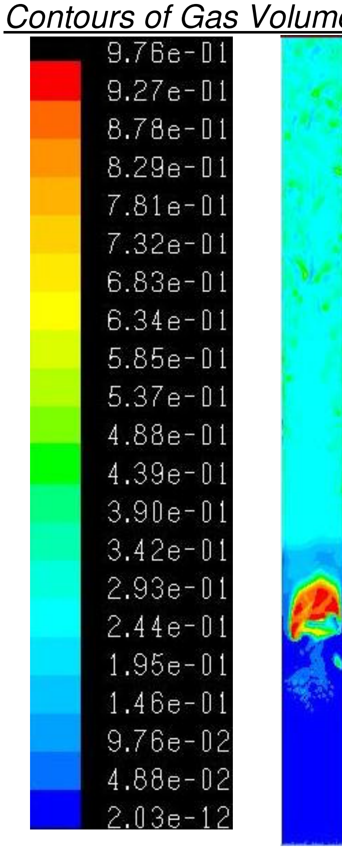


fig-6.113 t=15s

Contours of Absolute Pressure(mixture) (Pascal)

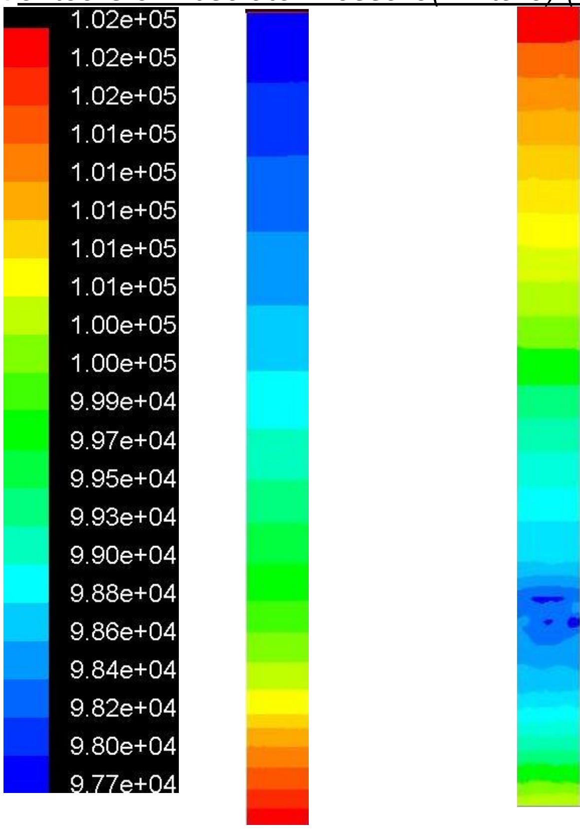


Fig-6.114 t=0s 15s

Magnitude of Velocity Vector of Solids

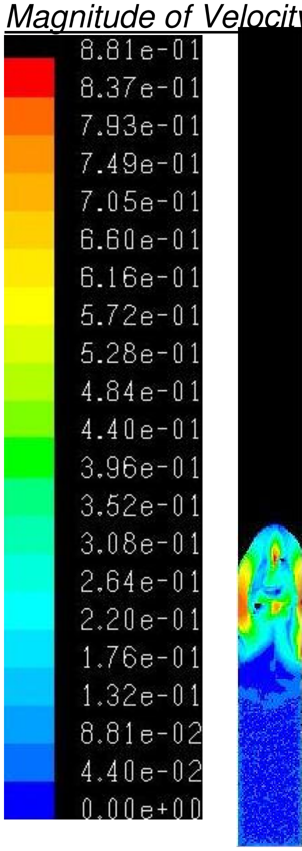


Fig-6.115 t=15s

Three-phase ;6%(w/w)Glecerol solutioncity;0.127m/sU_L & 0.051m/s U_G-

Contours of Solid Volume fraction

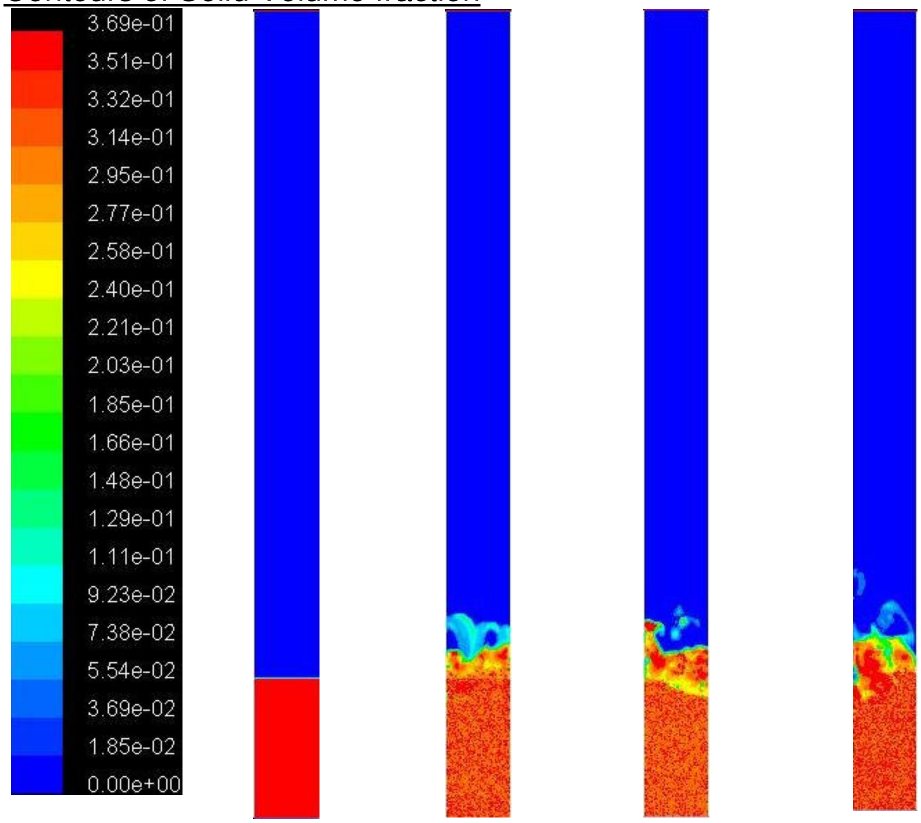


Fig-6.116 t= 0s 1.5s 3s 3.5s

Contours of Liquid Volume fraction

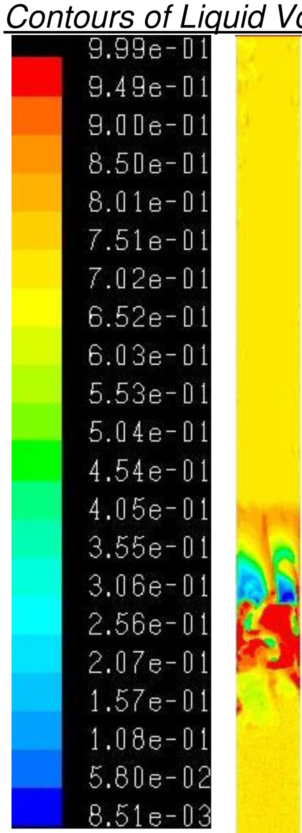


Fig-6.117 t=3.5s

Contours of Gas Volume fraction

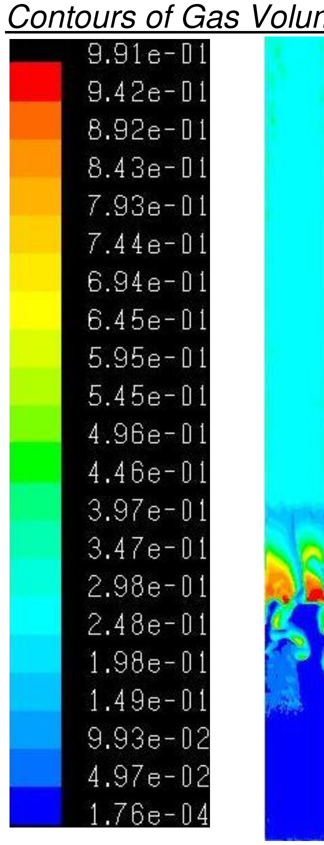


fig-6.18 t=3.5s

Contours of Absolute Pressure(mixture) (Pascal)

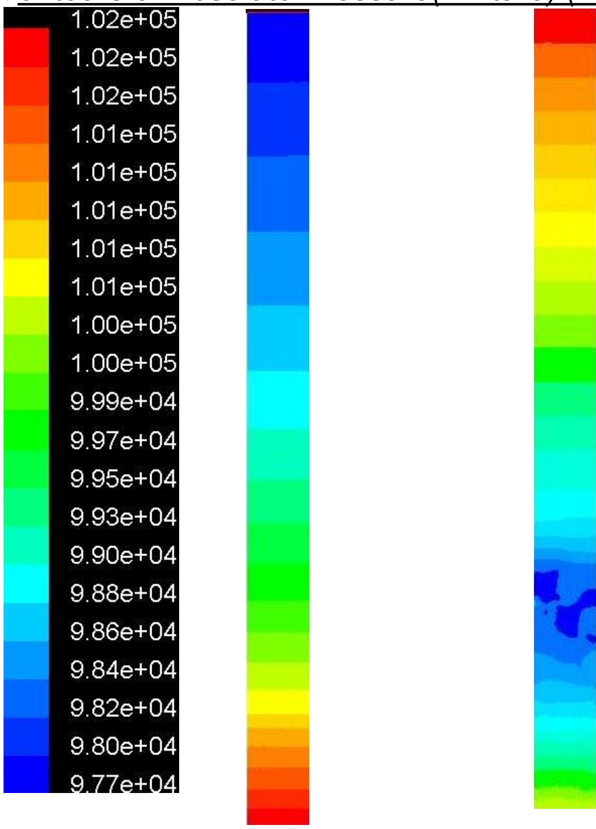


Fig-6.119 t=0s 3.5s

Magnitude of Velocity Vector of Solids

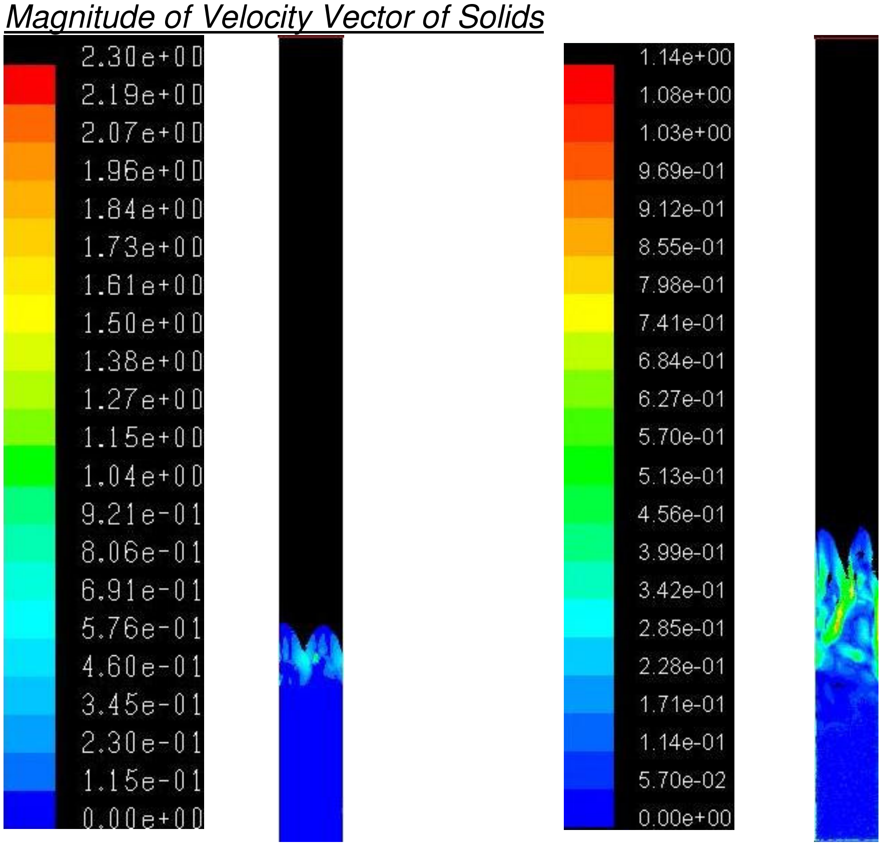


Fig-6.120 t=1.5s t= 3.5s

Bed Height from CFD Graphs-

For two phase and different bed materials-

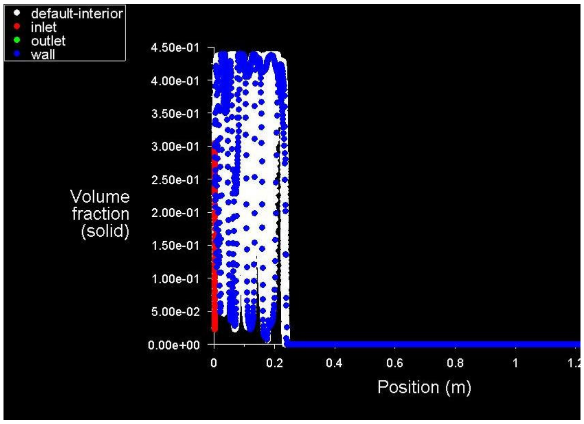


Fig-6.121-laterite at 0.127m/s U_L

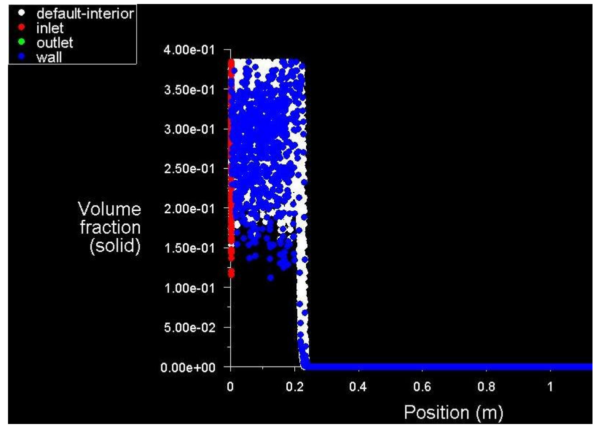


Fig-6.122-Iron ore at 0.149m/s U_L

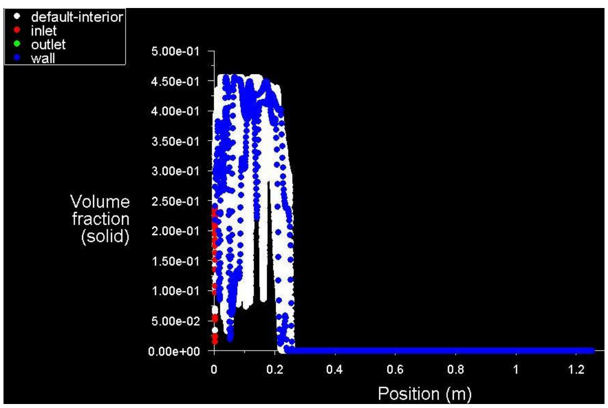


Fig-6.123-Coal at 0.064m/s U_L

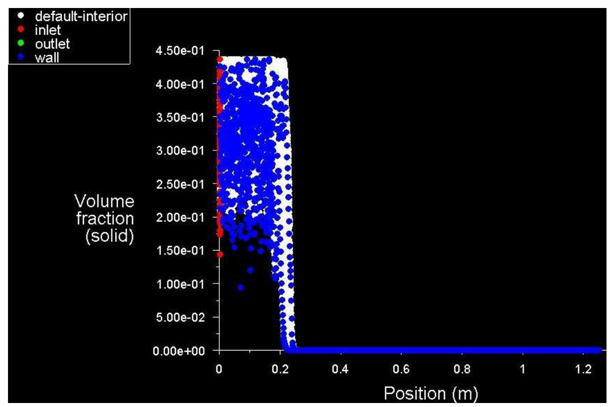


Fig-6.124-Dolomite at 0.12m/s U_L

For Three phase and different bed materials-

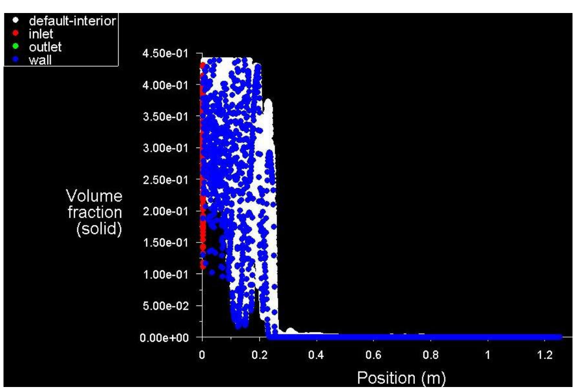


Fig-6.125-Laterite at 0.2m/s U_L & 0.051m/s U_G

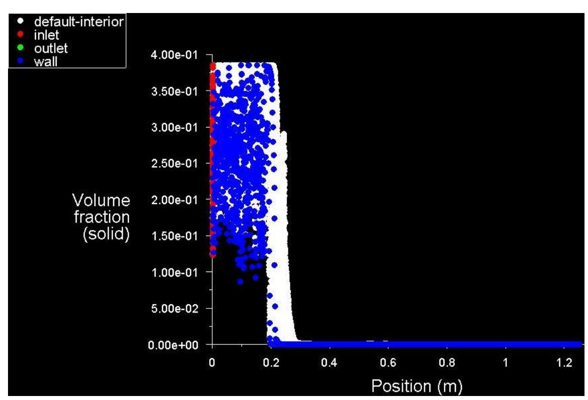


Fig-6.126-Iron Ore at 0.127m/s U_L & 0.051m/s U_G

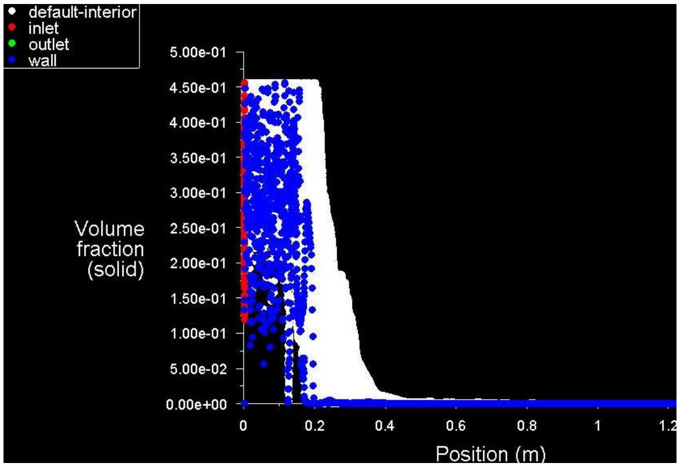


Fig-6.127-Coal at 0.0425m/s UL
& 0.051m/s UG

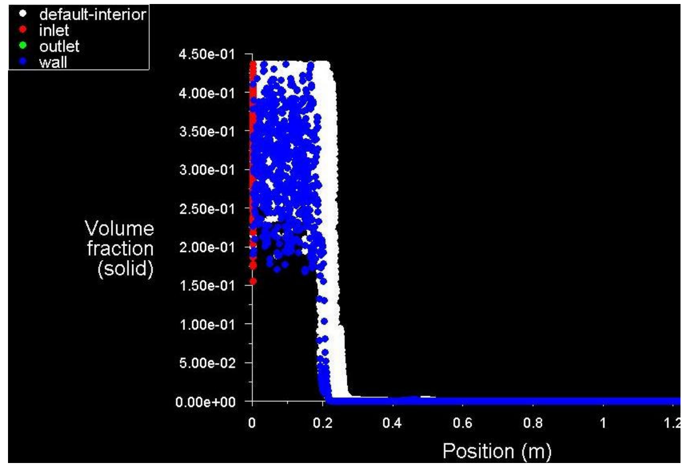


Fig-6.128-Dolomite at 0.106m/sUL
& 0.051m/s UG

For two phase and different Viscosity of Glycerol sol^n-

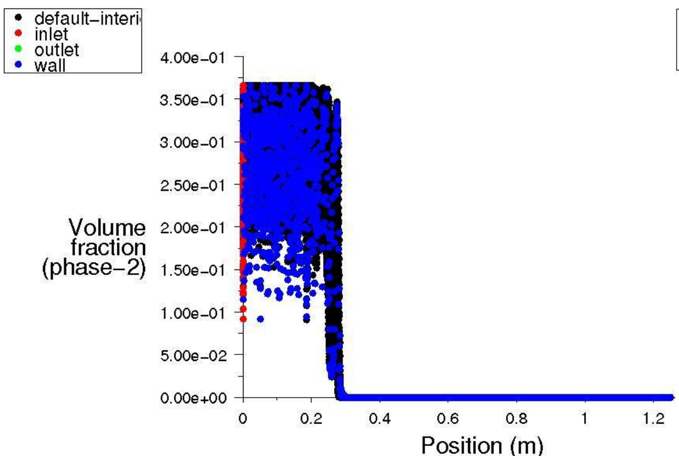


Fig-6.129-24% sol^n at 0.127m/s UL

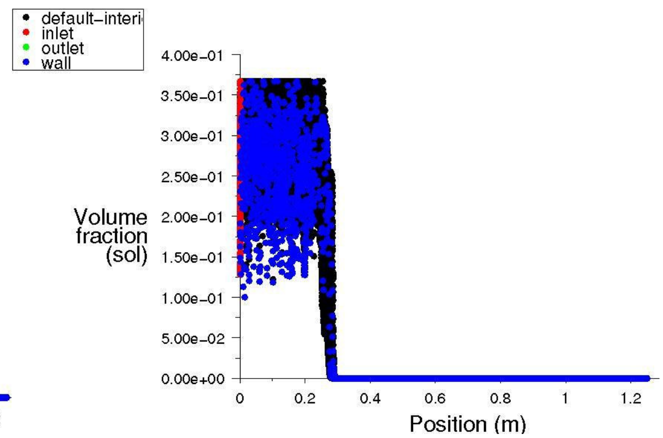


Fig-6.130-18% sol^n at 0.127m/s UL

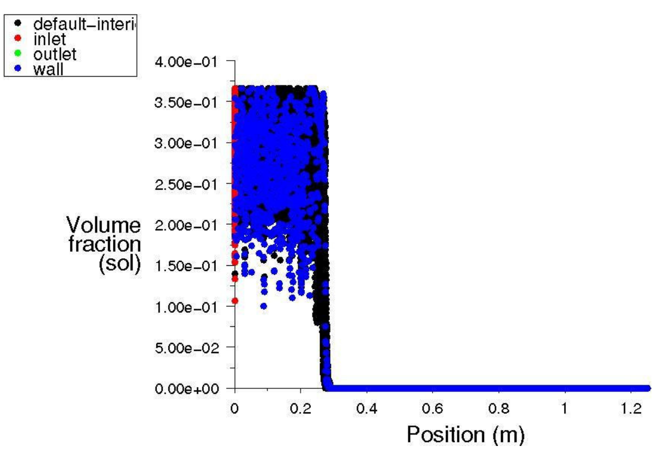


Fig-6.131-12% sol^n at 0.127m/s UL

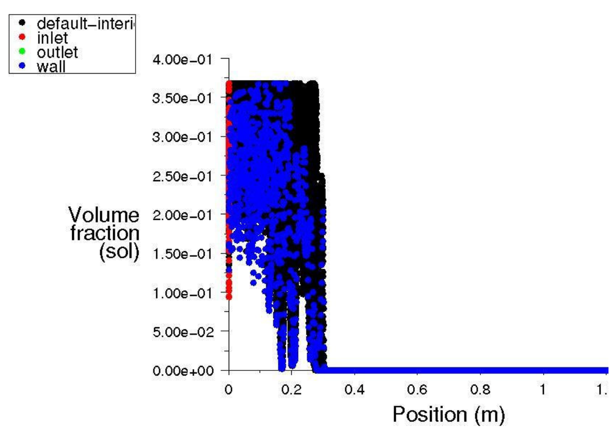


Fig-6.132-06% sol^n at 0.127m/s UL

For three phase and different Viscosity of Glycerol sol^n-

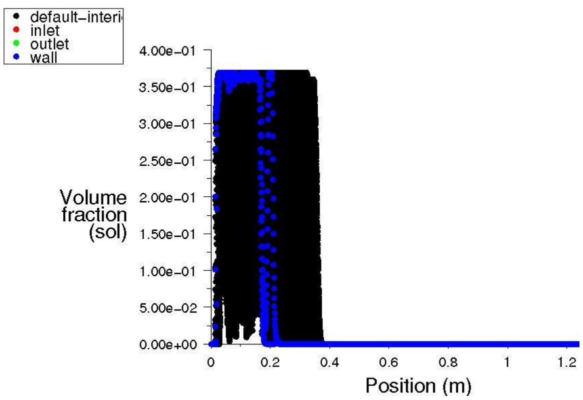


Fig-6.133-24% sol^n at 0.085m/s U_L & 0.051m/s U_G

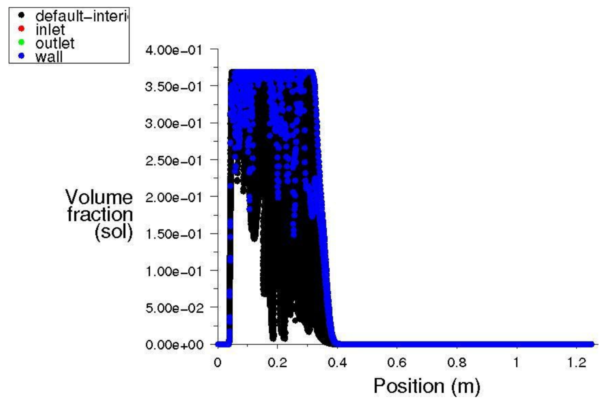


Fig-6.134-18% sol^n at 0.127m/s U_L & 0.051m/s U_G

Comments on the CFD results shown above:

Figures show the contours of solid, liquid and gas volume fraction; the variation of pressure drop and velocity vectors of solids along the length of the column. The diagrams obtained are useful in determining the material distribution in the column and also the pressure drop variation.

For velocities of liquids below fluidization velocity, the solids didn't move much and it is a good result obtained. For minimum fluidization velocity, the diagram showed bed lifting after some time steps. Furthermore for velocities above minimum liquid fluidization velocity, there was no increase in the height of the solids as evident from the diagram. Hence Fluent has the ability to predict the results by simulating the given problem into software.

During the course of the software, we used different materials and liquids which involved a lot of cost. The results obtained were matching with the experimental one so Fluent is able to save the material and equipment cost; at the same time it gives us the flexibility to change the equipment dimensions and material properties. So a pilot scale experiment can be converted into an industrial one with the support from Fluent

Fig. 6.121 to 6.134 shows the bed height at a particular velocity of liquid and gas. The results deviate from the experimental one by a margin of +/- 5%.

We would like to conclude that the results obtained from Fluent are promisable and the software can be used for Industrial Chemical engineering practice so as to carry out safe and effective operations.

CHAPTER 7

CONCLUSIONS

The following conclusions are drawn from the experimental results obtained.

1. With increase in particle density the minimum fluidization velocity increases. The pressure drop is higher for bed with higher density bed material. The pressure drop becomes constant after minimum fluidization velocity.
2. The expansion ratio H/H_s increases with decrease in particle density. Also for same expansion ration the superficial velocity increases with increase in density of material
3. The minimum liquid fluidization velocity increases with increase in particle density
4. The bed expansion ratio is low for low density bed material. Bed expansion is a strong function of liquid superficial velocity for a particular bed material.
5. Pressure drop is not a strong function of liquid superficial velocity.
6. Particle density is a strong function of minimum fluidization velocity as evident from the graph
7. With increase in liquid viscosity and density the pressure drop decreases. At the same time minimum fluidization velocity increases with decrease in liquid viscosity
8. For same liquid superficial velocity, the expansion ratio $H/H_{s\ \mathrm{increases}}$ with increase in liquid viscosity. Also for same expansion ratio the liquid superficial velocity increases with decrease in liquid viscosity.
9. The minimum liquid fluidization velocity decreases with increase in viscosity
10. Gas hold up decreases with increase in liquid superficial velocity
11. The gas hold up is higher for higher viscosity fluid. It is low for water and increases as the viscosity increases. Hence it is strong function of liquid viscosity.
12. The bed expansion ratio is higher for higher viscosity fluid and it is a strong function of liquid superficial velocity though effect of changing the viscosity didn't have much effect on expansion ratio.
13. The pressure drop is influenced by the initial static bed height, bed expansion, particle size and density as well as the viscosity of the fluidizing medium.

14. The results obtained from Fluent were promising and it showed good predictions for pressure drop, bed height with considerable accuracy.

NOTATIONS:

Q_L Liquid flow rate in LPM

Q_G Gas flow rate in LPM

U_L Liquid superficial velocity

U_G Gas superficial velocity

Hs Bed static height in cm

H Bed height in cm

H/Hs Bed expansion ratio

H-CCl_4 Height of CCl_4 in manometer

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